autocorrelatable form of modulation, said modulator providing the modulated CW optical fiber to the span; **an optical receiver joined to said span and capable of receiving a retrieved optical signal returned therefrom, wherein the retrieved optical signal comprises back-propagating portions of the illumination from sensing zone segments, said receiver operative to produce a radio frequency (r.f.) counterpart signal of the retrieved optical signal**; and **a processor operative to detect a reiterative autocorrelatable form of modulation from the counterpart signal in a corresponding plurality of different timed relationships with respect to the reiterative autocorrelatable form of modulation of the CW optical signal to give at least one signal for each zone segment.** **Pending Claim 25**: 25. The system of claim 23, **wherein said span has a length L and said light source is a laser having the capability to generate a lightwave signal with sufficient stability to retain coherency in propagation along said span for a distance at least equal to two times length L**. **Pending Claim 26**: 26. The system of claim 25, **wherein the length L of said span is at least about 5 km**. **Pending Claim 27**: 27. The system of claim 23, **wherein said**	**remote end**; **a first light source for producing a coherent carrier lightwave signal of a first predetermined wavelength**; **a spectrum spreading signal modulator for temporally structuring said carrier lightwave signal into a spread spectrum modulated interrogation lightwave signal which continuously reiterates sequences of an autocorrelatable spectrum spreading signal, the reiterated sequences being executed in a fixed relationship to a predetermined timing base**; **a lightwave heterodyner having first and second inputs for receiving a primary signal and a local oscillator signal, respectively, and operative to produce the beat frequencies of their respective frequencies**; a lightwave directional coupler having a first port which receives said spread spectrum modulated interrogation lightwave signal, a second port coupled to said first end of said optical fiber span, and a third port coupled to said primary signal input of the heterodyner; said directional coupler coupling said spread spectrum modulated interrogation lightwave signal to said second port where it is launched in a forwardly propagating direction along said optical fiber span **causing the return to said second port of a composite back-propagating lightwave which is a summation of lightwave back-propagations from a continuum of locations along the length of the span, said composite back-propagating lightwave signal** comprising a summation of multiple components including; a first signal component comprising the

light source is a planar, ring-type laser. **Pending Claim 28**: 28. The system of claim 23, **wherein said span of optical fiber comprises a single mode fiber optic cable**. **Pending Claim 29**: 29. The system of claim 23, **wherein said span of optical fiber is made from the polarization preserving type of optical fiber**. **Pending Claim 30**: 30. The system of claim 23, **wherein said span of optical fiber span has a coating made of a thermoplastic material having the combined characteristics of a low Young's modulus and a Poisson's ratio below that of natural rubber, wherein the coating enhances the longitudinal component of strain variation derived from an acoustic wave signal whose wave front is incident to the optical fiber span from a direction at least in part having a lateral component in the direction along which the wave front propagates**.	summation of portions of the said spread spectrum modulated interrogation lightwave signal which the innate properties of the optical fiber cause to backpropagate at a continuum of locations along the span; and a second signal component comprising the modulation of said first signal component caused by longitudinal components of optical path changes induced into said span at a continuum of locations along said span by external physical signals, said second signal component further including a corresponding set of n subcomponents comprising the modulation of said first signal component by optical path changes caused by said external signals at the respective sensing positions; **said directional coupler coupling said composite back-propagating lightwave to said third port where it is applied to said first input of the heterodyner**; a second light source coupled to said second input of the lightwave heterodyner, said second light source producing a coherent local oscillator lightwave signal in phase locked relation to said carrier lightwave signal and of a second predetermined wavelength which differs from the first predetermined wavelength by an amount of difference small enough **to produce at the output of the heterodyner a radio frequency (r.f.) composite difference beat signal, but by an amount large enough to cause said r.f. composite difference beat signal to have sufficient bandwidth to cause it to include r.f. counterparts of signal components and subcomponents of said composite back-propagating lightwave signal**; **said r.f. composite difference beat signal being coupled to an n-way splitter**

	providing a corresponding set of n output channels, each transmitting said r.f. composite difference beat signal; **a corresponding set of n de-spreaders and de-multiplexers having their respective inputs connected to the corresponding output channels of said n-way splitter through a corresponding set of time delay circuits which respectively provide a corresponding set of predetermined time delays in relation to said predetermined timing base of the spectrum spreading signal modulator, to establish said n desired sensing positions along said optical fiber span**; **and** **said set of r.f. de-spreaders and de-multiplexers concurrently serving multiple functions including**: **a first function of performing a coherent signal correlation process upon said r.f. composite difference beat signal to de-spread the r.f. counterparts of the interrogation lightwave signal**; and **a second function of conjunctively temporally and spatially demultiplexing said r.f. composite difference beat signal to provide at their respective outputs r.f. counterparts of the subcomponents of said second signal component of said composite back-propagating lightwave signal caused by changes in the optical path within said optical fiber span induced by external physical signals respectively coupled to the optical fiber span at corresponding sensing positions.** **Patent Claim 4**: 4. The reflectometer of claim 1 **wherein said**

	type of external physical signal which induces light path changes in said optical fiber span is an acoustic pressure wave signal. **Patent Claim 6**: 6. The reflectometer of claim 5, **wherein: said optical fiber span is of a length L; and said first light source is a laser having the performance capability to generate a lightwave signal with sufficient phase stability to substantially retain coherency in propagation along said optical fiber span for a distance at least equal to 2L**. **Patent Claim 7**: 7. The reflectometer of claim 6, **wherein the length L of said optical fiber span is at least 5 km**. **Patent Claim 8**: 8. The reflectometer of claim 7, **wherein said light source is a planar, ring-type laser**. **Patent Claim 9**: 9. The reflectometer of claim 7, **wherein said optical fiber span comprises a single-mode fiber optic cable**. **Patent Claim 22**: 22. The method of claim 4, **wherein said optical fiber span comprises a fiber optic cable of the polarization preserving type**.

	Patent Claim 23: 23. The reflectometer of claim 4, **wherein: said optical fiber span has a coating made of a thermoplastic material having the combined characteristics of a low Young's modulus and a Poisson's ratio below that of natural rubber, and said coating serving to enhance the longitudinal component of strain variation derived from an acoustic wave signal** whose wave front is incident to the span from a direction at least in part having a lateral component in the direction along which the wave front propagates. **Patent Claim 26**: 26. The reflectometer of claim 1, **wherein said type of external physical signal which induces light path changes in said optical fiber span is a selected one of a group consisting of:** (i) a seismic signal wherein with the media which couples the signal to said optical fiber span includes at least in part the ground in which the fiber optic span is buried; (ii) **an underwater sound signal wherein the media which couples the signal to said optical fiber span includes at least in part a body of water in which the fiber optic span is immersed**; (iii) an electromagnetic force field coupled to the optical fiber span; (iv) a signal comprising temperature variations coupled to the optical fiber span; and (v) at least one microphonic signal which is coupled to said optical fiber span at an at least one of said set of n sensing positions along the optical fiber span. **Patent Claim 27**:

	27. The reflectometer of claim 1, wherein each of: (i) **said coherent carrier lightwave signal**; (ii) said coherent local oscillator lightwave signal; (iii) said spread spectrum modulated interrogation lightwave signal; (iv) said composite back-propagating lightwave signal; (v) said radio frequency (r.f.) composite difference beat signal; and (vi) each counterpart of said r.f. counterpart of the subcomponents of said second signal component of said composite back-propagating lightwave signal, **is a continuous wave (CW) signal**. **Patent Claim 31**: 31. **A system** wherein, at respective span sensing stations of a plurality of sensing stations along a span of optical fiber, **the system senses input signals of a type having a property of inducing light path changes at regions of the span influenced by such input signals,** comprising: **means for illuminating an optical fiber span with a CW optical signal**; **means for retrieving back-propagating portions of the illumination back propagating from a continuum of locations along the span**; **means for modulating said CW optical signal with a reiterative binary psuedonoise code sequence in a manner which further temporally structures the modulated CW optical signal into a spread spectrum reiterative binary psuedonoise code sequence signal**; **means for picking off a radio frequency (r.f.) counterpart of the retrieved signal, wherein the r.f. counterpart is in phase**

	locked synchronism with the CW optical signal; **means for performing a corresponding plurality of coherent autocorrelation detection processes upon said r.f. counterpart of the retrieved optical signal to conjunctively perform correlation detection and dispreading of the r.f. counterparts in the respective autocorrelation detections of the plurality of autocorrelation detection processes in a corresponding plurality of different timed relationships with respect to the reiterative autocorrelatable form of modulation of the CW optical signal**. **Patent Claim 32**: 32. **Signal sensing array apparatus**, for sensing input signals at an array of **a plurality of sensing stations along an optical fiber span, wherein at respective sensing stations of the array the apparatus senses input signals of a type having a property of inducing light path changes within influenced by such input signals**, said apparatus comprising: an optical wave network comprising **a transmitter laser** and a lightwave directional coupler, said network being **operative to illuminate an optical fiber span with a CW optical signal** and to retrieve portions of the illumination back-propagating from a continuum of locations along the fiber span; **a modulator operative to modulate and temporally structure the CW optical signal into a CW optical signal with a reiterative spread spectrum form of binary psuedonoise code sequence form of modulated signal**;

	a heterodyner which, in phase locked synchronism with said transmitter laser, receives said retrieved back-propagated portions of illumination and derives therefrom a radio frequency (r.f.) counterpart; and **a corresponding plurality of autocorrelation detectors operative to respectively perform coherent correlation processes upon said r.f. counterpart of the retrieved optical signal to conjunctively perform correlation detection and dispreading functions therewith, in respective timed relationships of a corresponding plurality of different timed relationships with respect to said reiterative autocorrelatable form of modulation code**.

The Examiner finds that claims 23 and 25-30 of the '161 Reissue Proceedings have essentially the same claim requirements as the *'863 ODP Claims*, just somewhat broader. (See comparison above). In addition, where claims 23 and 25-30 of the '161 Reissue Proceedings and the *'863 ODP Claims* are not exactly the same, the Examiner finds that claims 23 and 25-30 of the '161 Reissue Proceedings would be obvious variants to one of ordinary skill in the art based on engineering expediency of the *'863 ODP Claims*.

Claim 24 is rejected on the ground of nonstatutory double patenting as being unpatentable over the ***'863 ODP Claims*** of the '863 patent in view of ***Kersey et al.'806*** (U.S. Patent No. 6,285,806).[35]

XIV. Claim Rejections - 35 USC § 102

The following is a quotation of the appropriate paragraphs of pre-AIA 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless –
>
> (b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.

Claims 23-25 and 31-33 are rejected under pre-AIA 35 U.S.C. 102(b) as being anticipated by ***Kersey et al.'806*** (U.S. Patent No. 6,285,806).

With respect to claim 23, *Kersey et al.'806* discloses

[a] system comprising:

In this regard, the Examiner finds that *Kersey et al.'806* discloses a system **200** for detecting an acoustic signal. (*Kersey et al.'806* Abstract; c.1, ll.6-10; see Figure 2). The Examiner finds that *Kersey et al.'806* discloses light path changes induced by conditions to be sensed (*i.e.*, acoustic waves, temperature change, stress and strain) provide a measurement of the conditions to be sensed. (*Id.* c.1, ll.15-19; c.2, ll.6-10; c.3, ll.46-49).

Thus, the Examiner concludes that *Kersey et al.'806* sufficiently discloses *[a] system.*

[35] See the pre-AIA 35 U.S.C. 103(a) rejection of claims 24 and 32 over *Kersey et al. '806* below for *prima facie* teachings of claim requirements and obviousness.

a span of optical fiber having sensing zone segments wherein signals incident to said span have a property of inducing light path changes at sensing zone segments that result in a back-propagating signals wherein each zone segment has a specialized sensing function;

In this regard, the Examiner finds that *Kersey et al.'806* discloses a fiber sensory array **200** comprising a span of optical fiber **214** having sensing zone segments (*Kersey et al.'806* Bragg grating reflectors **218-0 – 218-N** with coils **216-1 – 216N**) with signals (sum of reflected light fluxes; *id.* c.3, ll.56-57) incident to the span **214** having a property of inducing light path changes at the sensing segments/regions (Bragg grating reflectors **218-0 – 218-N** with coils **216-1 – 216N**) of the span **214** that result in a back-propagating signal. (*Id.* c.3, ll.40-49, 54-57; see Figure 2). The Examiner finds that *Kersey et al.'806* discloses light path changes induced by conditions to be sensed (*i.e.*, acoustic waves, temperature change, stress and strain) provide a measurement of the conditions to be sensed. (*Id.* c.1, ll.15-19; c.2, ll.6-10; c.3, ll.46-49)

Thus, the Examiner concludes that *Kersey et al.'806* sufficiently discloses *a span of optical fiber having sensing zone segments wherein electromagnetic signals incident to said span have a property of inducing light path changes at sensing zone segments that result in a back-propagating signals* wherein each zone segment has a specialized sensing function.

a light source operative to provide a continuous wave (CW) optical signal;

In this regard, the Examiner finds that *Kersey et al.'806* discloses a laser **202** that emits light having a long coherence length and a narrow wavelength range. (*Kersey et al.'806* c.3, ll.56-57).

Thus, the Examiner concludes that *Kersey et al.'806* sufficiently discloses *a light source operative to provide a continuous wave (CW) optical signal.*

a modulator operative to modulate the CW optical signal with a reiterative autocorrelatable form of modulation, said modulator providing the modulated CW optical fiber to the span;

In this regard, the Examiner finds that *Kersey et al.'806* discloses a phase modulator **208** that modulates a flux provided by the laser **202** with a Pseudo-random bit sequence ("PRBS") generated by generator **206** to produce a PRBS optical signal **210**. (*Id.* c.3, ll.35-46; see Figure 2). The Examiner finds that the generator **206** produces the PRBS which is provided to both the phase modulator **208** to produce a PRBS optical signal **210** and the delay circuit **228** and correlation circuit **230** combination. The Examiner finds that the PRBS is the reiterative autocorrelatable form of modulation.

Thus, the Examiner concludes that *Kersey et al.'806* sufficiently discloses *a modulator operative to modulate the CW optical signal with a reiterative autocorrelatable form of modulation, said modulator providing the modulated CW optical fiber to the span.*

an optical receiver joined to said span and capable of receiving a retrieved optical signal returned therefrom, wherein the retrieved optical signal comprises back-propagating portions of the illumination from sensing zone segments, said receiver operative to produce a radio frequency (r.f.) counterpart signal of the retrieved optical signal;

In this regard, the Examiner finds that *Kersey et al.'806* discloses an optical receiver (combination coupler **220**, transducers **22** and **224**, and amplifier **226**) joined to said span **214** and capable of receiving a retrieved optical signal returned therefrom (sum of reflected light fluxes; *id.* c.3, ll.56-57), wherein the retrieved optical signal comprises back-propagating portions of the illumination from the sensing segments/regions (Bragg grating reflectors **218-0** – **218-N** with coils **216-1** – **216N**), said receiver (combination coupler **220**, transducers **22** and **224**, and amplifier **226**) operative to produce a radio frequency (r.f.) counterpart signal (output signal **227**) of the retrieved optical signal. (*Id.* c.3. l.54 – c.4, l.8; see Figure 2). The Examiner finds that that *Kersey et al.'806* discloses that heterodyne processing can also can be incorporated into the system for demodulation. (*Id.* c.5, ll.7-13).

Thus, the Examiner concludes that *Kersey et al.'806* sufficiently discloses *an optical receiver joined to said span and capable of receiving a retrieved optical signal returned therefrom, wherein the retrieved optical signal comprises back-propagating portions of the illumination from sensing zone segments, said receiver operative to produce a radio frequency (r.f.) counterpart signal of the retrieved optical signal, wherein the counterpart signal is in phase locked synchronism with the CW optical signal.*

a processor operative to detect a reiterative autocorrelatable form of modulation from the counterpart signal in a corresponding plurality of different timed relationships with respect to the reiterative autocorrelatable form of modulation of the CW optical signal to give at least one signal for each zone segment.

In this regard, the Examiner finds that *Kersey et al.'806* discloses a processor (correlation circuit **230/230-1 – 230-N**) to detect a reiterative autocorrelatable form of modulation (PRBS generated by generator **206**) from the counterpart signal (output signal **227**) in a corresponding plurality of different timed relationships (delay circuit **228/228-1 – 228-N** outputs to correlator **230/230-1 – 230-N**) with respect to the reiterative autocorrelatable form of modulation (PRBS generated by generator **206**) of the CW optical signal (PRBS optical signal **210**) to give a measurement (ϕ/ϕ_1- ϕ_3) representative of the electromagnetic field proximate to at least one zone segment (Bragg grating reflectors **218-0 – 218-N** with coils **216-1 – 216N**). (*Id.* c.4, l.8 – c.5, l.6;

see Figures 2, 3). The Examiner finds that the 'electromagnetic signals' inherently have an effect on the fiber optic span of *Kersey et al.'806*, as evidence by *Kersey et al.'986.*[36]

Thus, the Examiner concludes that *Kersey et al.'806* sufficiently discloses *a processor operative to detect a reiterative autocorrelatable form of modulation from the counterpart signal in a corresponding plurality of different timed relationships with respect to the reiterative autocorrelatable form of modulation of the CW optical signal to give at least one signal for each zone segment.*

<u>With respect to claim 24</u>, *Kersey et al.'806* discloses

wherein at least one zone segment of said span is helically disposed.

In this regard, the Examiner finds that *Kersey et al.'806* discloses zone segments of the span of optical fiber **214** having coils helically disposed (*Kersey et al.'806* Bragg grating reflectors **218-0** – **218-N** with coils **216-1** – **216N**).

Thus, the Examiner concludes that *Kersey et al.'806* sufficiently discloses *wherein at least one zone segment of said span is helically disposed.*

<u>With respect to claim 25</u>, *Kersey et al.'806* discloses

wherein said span has a length L and said light source is a laser having the capability to generate a lightwave signal with sufficient stability to retain coherency in propagation along said span for a distance at least equal to two times length L.

In this regard, the Examiner finds that *Kersey et al.'806* discloses the span of optical fiber

[36] See rejection of claim 23 above for explanation of electromagnetic field sensing inherency (emphasis on "system" element).

214 having a length L. (*Id.* Figure 2). The Examiner finds that *Kersey et al.'806* discloses the light source being a laser **202** having a long coherence length and a narrow wavelength range. (*Id.* c.3, ll.29-31). The Examiner finds that the laser **202** emits light that is modulated by phase modulator **208**, propagated up the entirety of the optical fiber **214**, and reflected back from the Bragg grating reflectors **218-0** – **218-N/**coils **216-1** – **216N** combinations. Since the PRBS optical signal **210** is propagated down the entirety of the optical fiber **214** and back as indicated in Figure 2, the Examiner finds laser **202** inherently has the capability to generate a lightwave signal with sufficient phase stability to substantially retain coherency in propagation along said span for a distance at least equal to two times length L.

Thus, the Examiner concludes that *Kersey et al.'806* sufficiently discloses *wherein said span has a length L and said light source is a laser having the capability to generate a lightwave signal with sufficient stability to retain coherency in propagation along said span for a distance at least equal to two times length L.*

With respect to the limitations of claim 31, The Examiner finds that claim 31 is a method claim for performing the functions of the apparatus of claim 25. Thus, the Examiner concludes that the apparatus of claim 25 performs the method steps of claim 31. (See rejection of claim 23 above).

With respect to the limitations of claim 32, The Examiner finds that claim 32 is a method claim for performing the functions of the apparatus of claim 24. Thus, the Examiner concludes that the apparatus of claim 24 performs the method steps of claim 32. (See rejection of claim 24 above).

<u>With respect to the limitations of claim 33</u>, The Examiner finds that claim 33 is a method claim for performing the functions of the apparatus of claim 25. Thus, the Examiner concludes that the apparatus of claim 25 performs the method steps of claim 33. (See rejection of claim 25 above).

XV. Rejections under 35 U.S.C. § 103

The following is a quotation of pre-AIA 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

The factual inquiries set forth in *Graham v. John Deere Co.*, 383 U.S. 1, 148 USPQ 459 (1966), that are applied for establishing a background for determining obviousness under pre-AIA 35 U.S.C. 103(a) are summarized as follows:

1. Determining the scope and contents of the prior art.

2. Ascertaining the differences between the prior art and the claims at issue.

3. Resolving the level of ordinary skill in the pertinent art.

4. Considering objective evidence present in the application indicating obviousness or nonobviousness.

<u>Claims 26 and 34</u> are rejected under pre-AIA 35 U.S.C. 103(a) as being unpatentable over ***Kersey et al.'806*** (U.S. Patent No. 4,889,986) in view of ***Taylor et al.*** (U.S. Patent No. 5,194,847) and ***Farhadiroushan*** (U.S. Patent No. 5,754,293).

In this regard, *Kersey et al.'806* discloses all the limitations, as previously set forth, except for specifically calling for the length L of said span being at least about 5 km.

However, a fiber optic sensing device having the length L of the span being at least about 5 km is known in the art. The Examiner finds that *Taylor et al.*, for example, teaches the length of a fiber optic span of fiber optic sensor device being as long as 50 km. (*Taylor et al.* c:4, ll.37-40, 47-64; see Figure 3).

The Examiner finds that that it would have been obvious to one of ordinary skill in the art at the time of the invention was made to incorporate for the length L of said span being at least about 5 km as described in *Taylor et al.* in the system of *Kersey et al.'806*.

A person of ordinary skill in the art would be motivated to provide the length L of at least about 5 km for the optical fiber span since it is desired length for both linear acoustic and pipeline sensory arrays. (*Farhadiroushan* c:1, ll.33-46). In other words, such a modification would have provided a system for detecting signals of a large number of sensors in acoustic and pipeline application, thus increasing the overall versatility of the fiber optic sensor system.

Thus, the Examiner concludes that *Kersey et al.'806*, *Taylor et al.* and *Farhadiroushan* teaches and/or renders obvious the limitations of *the length L of said span being at least about 5 km*.

Claims 27 and 35 are rejected under pre-AIA 35 U.S.C. 103(a) as being unpatentable over ***Kersey et al.'806*** (U.S. Patent No. 4,889,986) in view of ***Nilsson*** (U.S. Patent No. 5,177,764).

In this regard, *Kersey et al.'806* explicitly discloses the light source being a laser **202** that emits light having a long coherence length and a narrow wavelength range. (*Kersey et al.'806* c.3, ll.56-57). While *Kersey et al.'806* discloses the light source being a laser **202** (*id.*), *Kersey et al.'806* is silent to the laser being a planar, ring-type laser.

However, a light source that is a planar, ring-type laser is known in the art. The Examiner finds that *Nilsson*, for example, teaches a planar ring-type laser light source (*Nilsson* Abstract; c.4, ll.5-42; whole document).

The Examiner finds that that it would have been obvious to one of ordinary skill in the art at the time of the invention was made to incorporate the planar, ring-type laser as described in *Nilsson* in the system of *Kersey et al.'806*.

A person of ordinary skill in the art would be motivated to provide the planar, ring-type laser, since it has an optimized differential loss and is frequency tunable. (*Id.*) In other words, such a modification would have provided a system for detecting an acoustic signal that utilizes a unidirectional laser that is frequency tunable, optimized and simple to operate, thereby operational efficient.

Thus, the Examiner concludes that *Kersey et al.'806* and *Nilsson* teaches and/or renders obvious the limitations of *wherein said light source is a planar, ring-type laser*.

<u>Claims 28 and 36</u> are rejected under pre-AIA 35 U.S.C. 103(a) as being unpatentable over ***Kersey et al.'806*** (U.S. Patent No. 6,285,806) in view of ***Groves-Kirkby*** (UK Publication No. GB 2372100 A) and ***Bailey et al.*** (U.S. Patent No. 6,626,043).

In this regard, *Kersey et al.'806* discloses all the limitations, as previously set forth, except for specifically calling for the span of optical fiber comprising a single mode fiber optic cable.

However, a span of optical fiber comprising a single mode fiber optic cable is known in the art. The Examiner finds that *Groves-Kirkby*, for example, teaches a fiber optic waveguide Bragg grating system for sensing mechanical strain. (*Groves-Kirkby* Abstract; c. 2, ll.22-24; c. 4, ll.16-17). The Examiner finds that *Groves-Kirkby* teaches a fiber optic waveguide Bragg grating system comprising a preference to utilization of a single mode optical fiber (**1**, **2**, **100**) as the waveguide. (*Id.* at c. 2, l.15; c. 3, l.19; c.6, ll.14-16; c.10, ll.15-17).

The Examiner finds that that it would have been obvious to one of ordinary skill in the art at the time of the invention was made to incorporate the single mode optical fiber as described in *Groves-Kirkby* in the system to detect an electromagnetic field of *Kersey et al.'806.*

A person of ordinary skill in the art would be motivated to provide the single mode optical fiber, since it is preferred and considered a standard cable utilized in telecommunications. (*Groves-Kirkby* at c. 2, l.15; c. 3, l.19; and *Bailey et al.* at c.3, ll.54-59) In other words, such a modification would have provided a system for detecting an acoustic signal that utilizes a standard fiber optic cable that is already available for usage throughout industry, thereby reducing costs and increasing interfacing capabilities.

Thus, the Examiner concludes that *Kersey et al.'806*, *Groves-Kirkby* and *Bailey et al.* teaches and/or renders obvious the limitations of *wherein said span of optical fiber comprises a single mode fiber optic cable*.

Claims 29 and 37 are rejected under pre-AIA 35 U.S.C. 103(a) as being unpatentable over ***Kersey et al.'806*** (U.S. Patent No. 6,285,806) in view of ***Townley-Smith et al.*** (U.S. Publication No. 2005/0077455).

In this regard, *Kersey et al.'806* discloses all the limitations, as previously set forth, except for specifically calling for the span of optical fiber being made from the polarization preserving type of optical fiber.

However, a span of optical fiber being made from the polarization preserving type of optical fiber is known in the art. For examination purposes, the Examiner finds that polarization maintaining type is the same as polarization preserving type given its broadest reasonable interpretation (emphasis on 'maintaining' and 'preserving' being equivalent to one of ordinary skill in the art). In this light, the Examiner finds that *Townley-Smith et al.* teaches a fiber optic perimeter detection system for detecting intruders. (*Townley-Smith et al.* Abstract). The Examiner finds that *Townley-Smith et al.* teaches a stress sensing fiber **108** being of the polarization maintaining type. (*Id.* at ¶ 0077).

The Examiner finds that that it would have been obvious to one of ordinary skill in the art at the time of the invention was made to incorporate the polarization maintaining type fiber as described in *Townley-Smith et al.* in the system to detect an electromagnetic field of *Kersey et al.'806*.

A person of ordinary skill in the art would be motivated to provide the polarization maintaining type fiber, since it can increase the fiber optic sensor's sensitivity range when a change of stress is applied, and reduce some of the potential negative effects of fiber birefringence. (*Id.*) In other words, such a modification would have provided a more stress reactive sensor with reduced effects of birefringence, thereby increasing the sensitivity of the fiber used in a system for detecting an acoustic signals.

Thus, the Examiner concludes that *Kersey et al.'806* and *Townley-Smith et al.* teaches and/or renders obvious the limitations of *wherein said span of optical fiber is made from the polarization preserving type of optical fiber*.

Claims 30 and 38 are rejected under pre-AIA 35 U.S.C. 103(a) as being unpatentable over ***Kersey et al.'806*** (U.S. Patent No. 6,285,806) in view of ***Goldner et al***. (International Publication No. WO 2004/034096).

In this regard, *Kersey et al.'806* discloses all the limitations, as previously set forth, except for specifically calling for the span of optical fiber having a coating made of a thermoplastic material having the combined characteristics of a low Young's modulus and a Poisson's ratio below that of natural rubber, wherein the coating enhances the longitudinal component of strain variation derived from an acoustic wave signal whose wave front is incident to the optical fiber span from a direction at least in part having a lateral component in the direction along which the wave front propagates.

However, a span of optical fiber having a coating made of a thermoplastic material with the characteristics as set forth above is known in the art. For examination purposes, the Examiner finds that ‘971 patent discloses a thermoplastic elastomer as a material having the characteristics of claim 30. (‘971 patent; c.17, ll. 20-24).

In this light, the Examiner finds that *Goldner et al.* teaches a rugged fiber optic array that is utilized in hydrophone or geophone applications. (*Goldner et al.* Abstract). The Examiner finds that *Goldner et al.* teaches an optical fiber **17** being wound around a radial support rod **20** and the combination coated with a low modulus thermoplastic elastomer **21**. (*Id.* c.7, l. 29 – c.8, l.2; c.13, ll.3-13; claim 23; see Figures 1A, 1B).

The Examiner finds that that it would have been obvious to one of ordinary skill in the art at the time of the invention was made to include the low modulus thermoplastic elastomer coating on the fiber as described in *Goldner et al.* in the system of *Kersey et al.'806.*

A person of ordinary skill in the art would be motivated to provide the low modulus thermoplastic elastomer coating on the fiber, since it would block diffusion of water into the cable structure as well as provide as isolation from external stresses on the system that occur during the operation of the system. (Id. c.13, ll.6-13). In other words, such a modification would have provided a more fluid resistant and structurally resilient fiber optic cable, thereby increasing the operational longevity of the fiber used in a system for detecting an acoustic signals.

Thus, the Examiner concludes that *Kersey et al.'806* and *Goldner et al.* teaches and/or renders obvious the limitations of *the span of optical fiber [having] a coating made of a thermoplastic material having the combined characteristics of a low Young's modulus and a Poisson's ratio below that of natural rubber, wherein the coating enhances the longitudinal component of strain variation derived from an acoustic wave signal whose wave front is incident* *to the optical fiber span from a direction at least in part having a lateral component in the direction along which the wave front propagates.*

XVI. Conclusion

Applicant is respectfully reminded that any suggestions or examples of claim language provided by the Examiner are just that—suggestions or examples—and do not constitute a formal requirement mandated by the Examiner. To be especially clear, any suggestion or example provided in this Office Action (or in any future office action) does not constitute a formal requirement mandated by the Examiner.

Should Applicant decide to amend the claims, Applicant is also reminded that—like always—no new matter is allowed. The Examiner therefore leaves it up to Applicant to choose the precise claim language of the amendment in order to ensure that the amended language complies with 35 U.S.C. § 112 1st paragraph.

Independent of the requirements under 35 U.S.C. § 112 1st paragraph, Applicant is also respectfully reminded that when amending a particular claim, all claim terms must have clear support or antecedent basis in the specification. See 37 C.F.R. § 1.75(d)(1) and MPEP § 608.01(o). Should Applicant amend the claims such that the claim language no longer has clear support or antecedent basis in the specification, an objection to the specification may result. Therefore, in these situations where the amended claim language does not have clear support or antecedent basis in the specification and to prevent a subsequent 'Objection to the Specification' in the next office action, Applicant is encouraged to either (1) re-evaluate the amendment and change the claim language so the claims *do* have clear support or antecedent basis or, (2) amend the specification to ensure that the claim language does have clear support or antecedent basis. See again MPEP § 608.01(o) (¶3). Should Applicant choose to amend the specification, Applicant is reminded that—like always—no new matter in the specification is allowed. See 35 U.S.C. § 132(a). If Applicant has any questions on this matter, Applicant is encouraged to contact the Examiner via the telephone number listed below.

Applicant is reminded of the obligation to apprise the Office of any prior or concurrent proceedings in which the '971 patent is or was involved, such as interferences or trials before the Patent Trial and Appeal Board, other reissues, reexaminations, or litigations and the results of such proceedings.

In accordance with MPEP § 1406, the Examiner has reviewed and considered the prior art cited or 'of record' in the original prosecution of the '971 patent. Applicant is reminded that a listing of the information cited or 'of record' in the original prosecution of the '971 patent need not be resubmitted in this reissue application unless Applicant desires the information to be printed on a patent issuing from this reissue application.

Applicant is further reminded of the continuing obligation under 37 C.F.R. §1.56 to timely apprise the Office of any information which is material to patentability of the claims under consideration in this reissue application.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Stephen J. Ralis whose telephone number is (571)272-6227. The examiner can normally be reached on Monday - Friday, 8:00-5:00.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Timothy Speer can be reached on 571-272-8385. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

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SJR
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Notice of References Cited	Application/Control No. 14/686,161	Applicant(s)/Patent Under Reexamination PAYTON, ROBERT M	
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	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
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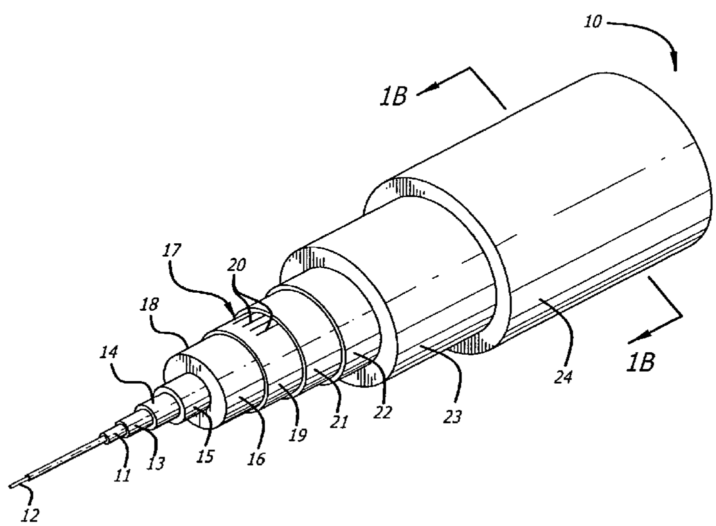
(54) **Title:** RUGGED FIBER OPTIC ARRAY



(57) **Abstract:** An array of fiber optic hydrophones or geophones is formed by winding of optical fiber around a continuous, yet flexible cylindrical core. The cylindrical core contains an elastomer filled with a specified percentage of voided plastic microspheres. The elastomer provides the necessary radial support of the optical fiber, and with the included voided microspheres, provides sufficient radial compliance under acoustic pressure for proper operation of the hydrophone. The cylindrical core can be made in very long sections allowing a plurality of fiber optic hydrophones to be wound onto it using a single optical fiber, with individual hydrophone elements separated by integral reflectors such as Fiber Bragg Gratings (FBSs). The center of the core may include a strength member and a central hollow tube for the passing of additional optical fibers. The aforementioned hydrophone array is then packaged within a protective outer coating or coatings as required for the specified application.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

RUGGED FIBER OPTIC ARRAY

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to U.S. Provisional Application Serial No. 60/416,007, filed October 4, 2002, U.S. Provisional Application Serial No. 60/463,295, filed April 16, 2003, and U.S. Provisional Application Serial No. 60/465,150, filed April 24, 2003, the entirety of which are expressly incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention:

The present invention relates generally to an improved design and construction technique for fiber optic hydrophones and hydrophone arrays. More specifically, the present invention comprises a fiber optic hydrophone that has a continuous solid, yet compliant, elastomer core. In some embodiments, plastic microspheres have been added to the elastomer core to provide increased acoustic compliance.

Description of Related Art:

There are many occasions when it is necessary to detect acoustic signals in an underwater environment. For example, geologic exploration is often carried out by setting small explosives below the ocean's, or other body of water's, surface, detonating the explosives, and then detecting the resulting acoustic signals to determine the structure of various features on or under the sea floor. Additionally, there is a need to be able to detect acoustic signals, such as the sounds emitted by ships, submarines, fish or other animals, that are transmitted under water.

Generally, where acoustic signals need to be sensed or detected in an underwater environment, sensors called hydrophones are used. In many instances, multiple hydrophones are joined together with a specified spacing between each hydrophone to form an array of hydrophones. Such arrays of multiple hydrophones are particularly useful compared to use of single hydrophones where it is necessary to determine the direction the acoustic signals are coming from, or to provide increased sensitivity so as to improve the likelihood of detecting faint acoustic signals.

Conventional hydrophone arrays consist of a series of many piezoelectric elements, or sensors, each of which produces a voltage proportional to the intensity of acoustic signals incident upon the hydrophone. Typical hydrophones available for use in such arrays at present have various circuitry or other electronics associated with the sensor elements located at each sensor in hydrophone. These associated circuits are used for amplification, filtering, digitization, multiplexing and the like of the signals produced by the piezoelectric sensors. Because these additional circuits or electronics are necessarily located underwater, the circuits and electronics are exposed to harsh conditions, such as extreme pressure due to the depth the hydrophone is deployed, or water leakage into the hydrophone housing. To protect the circuits, hydrophones typically include hermetically sealed armored housings. If the circuitry does fail, however, repair of the hydrophone requires that the hydrophone, or, as is typically the case, an entire array or portion of an array, may need to be retrieved from its underwater deployment for diagnosis and repair. Because such repairs are costly and time consuming, and may require the use of specialized vessels and equipment to retrieve the damaged hydrophones, there is a need for a more robust acoustic sensor.

One system that provides improved robustness and reliability uses fiber optic sensors as the sensor element in the hydrophone. Such fiber optic sensors typically use optical fiber wrapped in a high precision winding pattern around compliant, air-backed mandrels as the sensing medium. This arrangement is advantageous in that no additional circuitry or electronics are required at the location of the sensor, making the fiber optic sensors inherently more reliable than other types of conventional hydrophones used in hydrophone arrays.

In a fiber optic sensor, light is sent from a source located in a relatively benign environment through the optical fiber to the sensor. Acoustic pressure waves present in the water dynamically strain the fiber, resulting in a shift in the phase of the light transmitted in the optical fiber. The phase shifted light is compared to a reference signal, creating an interference pattern. The resulting light signal is then sent to an interrogator, which converts the light to an electrical signal for demodulation.

There are several shortcomings associated with presently available hydrophone arrays that use fiber optic sensors as the sensor element. One disadvantage of presently available fiber optic sensors is that the fiber generally is wrapped around discrete, hollow mandrels that are stiff enough to withstand the hydrostatic pressure requirements of deploying hydrophones under water, yet are compliant enough so that the acoustic pressure waves in the water can dynamically deform the mandrel, thereby straining the optical fiber resulting in a phase shift of the light transmitted through the fiber. Accordingly, the mandrels must be formed into sealed, relatively hard plastic or thin metal hollow cylinders that are leak proof against water under the required hydrostatic pressure. In general the mandrels used in presently available fiber optic sensors are stiff and unbendable. This is disadvantageous in that it is useful to be able to manufacture fiber optic sensor arrays in long continuous sections, and to store such arrays on circular drums, from which the fiber optic sensor array may be deployed and retrieved, and such long sections need to be flexible.

To facilitate the flexibility needed to store the fiber optic sensor arrays on a circular drum, the mandrels must be made into short cylindrical pressure vessels, such as, for example, capped tubes, with flexible links between the capped tubes to form long continuous bendable sections. A considerable amount of labor must be used to assemble the optic fiber wrapped on the air-backed mandrels into interferometers. This laborious process includes preparing the optical fiber, splicing and recoating the optical fiber, dressing the optical fiber, mechanically assembling the pressure vessels, and sealing and testing the vessels and optical fiber to ensure that the resulting assembly is water tight and functions as desired.

As fiber is wound around the long continuous, bendable sections, great care must be exercised to ensure that the mandrel/flexible link interfaces do not have any sharp or uneven surfaces, and do not separate, shift, or deform under pressure or tension, which will break the optical fiber. In addition, array strength members and extra optical fibers often must be placed along the outer surface of the continuous section, leading to optical fiber damage during reeling/unreeling operations as a result of friction, bending, crushing, and the like.

An additional shortcoming with air-backed mandrel optical fiber hydrophones is that such devices have a flat optical phase response to acoustic input as a function of acoustic frequency. This is disadvantageous in acoustic frequency ranges that contain unwanted acoustic signals, such as noise caused by fish, whales or other sound source, whose presence limits the dynamic range of the overall system unless very high sample rates are used by the system electronics to interrogate the sensors to allow signal analysis and canceling of the noise.

The spaces between and around the mandrels used for the fiber optic sensors may also be filled with a liquid in an attempt to provide improved acoustic coupling and thus sensor sensitivity as well as to improve or control the buoyancy of the array. Such construction may be disadvantageous because such liquid-filled fiber optic sensor arrays are susceptible to puncture during deployment and reeling operations as well as during normal operation, and leakage of the fluid typically results in failure of the array. Moreover, where a fluid such as kerosene or kerosene-like liquids or other possibly environmentally hazardous material is used, leakage of the fluid can contribute to unwanted pollution.

What has been needed, and heretofore unavailable, is a reliable, robust fiber optic acoustic sensor that has eliminates the disadvantages of air-backed or fluid filled arrays, yet provides for increased sensitivity and ease of manufacture. The present invention satisfies these and other needs.

SUMMARY OF THE INVENTION

The present invention overcomes many of the shortcomings associated with fiber optic hydrophone arrays manufactured in accordance with prior art methods.

The present invention eliminates the requirement for rigid, air-backed mandrels for the fiber optic hydrophones. Instead, long cylindrical segments of a continuously flexible elastomer form the base of the hydrophone structure. The optical fiber is wound onto the one-piece segments that are completely free of the rigid mandrel/flexible link interfaces and their associated problems. Compliance is provided to hydrophone through the use of voided plastic microspheres dispersed within the elastomer substrate. The hardness of the microsphere containing elastomer is controlled to meet the required acoustic sensitivity and the acoustic sensitivity versus depth requirements of a particular application.

One advantage of using an elastomer substrate is that the dynamic properties of the elastomer, such as, for example, bulk modulus and Poisson's ratio, may be altered as necessary to tailor the mechanical response of the sensor for an application. Such tailoring is useful, for example, to achieve mechanical roll-off of undesired (that, is, out of band) frequency response. The ability to suppress selected frequency ranges provides for limiting the bandwidth of the fiber optic sensors, reducing demands on the demodulation electronics, which historically require, using prior art sensors, sample rates that are orders of magnitude higher than that required to satisfy Nyquist criteria in order to maintain large dynamic ranges.

Further, replacing the individual sealed rigid mandrels with a flexible polymer allows the center core of the hydrophone or geophone segment to be used for passing extra optical fibers and/or a central strength member. Thus the central core of the hydrophone or geophone segment can be constructed similar to a standard high strength fiber optic telecommunications cable with the optical fiber protected in a thin metal tube surrounded by a rugged strength member and a tough outer jacket. Such a cable is inherently designed to withstand reeling/unreeling without stressing the optical fiber. In one embodiment of the present invention, the void filled elastomer is extruded on the outside of the core of the cable structure in a concentric fashion, thereby forming the base upon which to wind the optical fiber to form a hydrophone or array of hydrophones.

In another aspect of the present invention, the hydrophones of the present invention may be disposed within a hollow tube, with the remaining space within the tube filled with a liquid, as in a standard towed hydrophone array, or a low shear polymer compound that does not flow. The purpose of this filler is to isolate the hydrophones from longitudinal shear waves which cause noise in the output of the array.

In other aspects of the present invention, the outer surface of the hydrophone may be formed from a tough, abrasion resistant elastomeric cover, which provides turbulent boundary layer noise rejection. In one embodiment, microspheres may be added to the low shear polymer and/or the elastomeric cover as needed to adjust buoyancy of the hydrophone array. This embodiment is particularly advantageous in that the hydrophone may be used as is, that is, the fiber optic hydrophone may be towed without needing to be encased within a fluid filled tube, as is typical for fiber optic hydrophone arrays presently used.

In another aspect of the present invention, the hydrophone of the present invention may be constructed without the abrasion resistant cover. In one such embodiment, the hydrophone may be mounted within a fluid filled tube, as is typical in present towed hydrophone arrays.

In yet another aspect, the present invention is embodied in a continuous, flexible cylindrical device for detecting acoustic signals, comprising a flexible core including an acoustic substrate, an optical fiber wound around the acoustic substrate, and at least one periodic refractive index perturbation formed in the optical fiber. In another aspect, the acoustic substrate contains a plurality of voids. In still a further aspect, the voids are formed by hollow microspheres, which may be formed from a compliant material.

In still another aspect of the present invention, the flexible core includes a hollow tube for providing a passageway through the core. In one aspect, the flexible core includes a strength member for providing tensile strength to the core to resist stretching or breaking of the core during deployment, retrieval or use. In another aspect, the flexible core includes a strength member surrounding the hollow tube for providing tensile strength to the core to resist stretching or breaking of the core during deployment, retrieval or use.

Still another aspect of the present invention includes an intermediate jacket disposed between the metal tube and the central strength member. In one aspect, the jacket is disposed over the strength member.

In another aspect, the present invention includes an acoustic substrate including an elastomeric material having a selected dynamic property for limiting the sensor frequency response to within a desired range of frequencies.

In still another aspect, the optical fiber is wound under tension to form at least one optical hydrophone. In yet a further aspect, the present invention includes an embodiment wherein the optical fiber is wound under tension to form a plurality of optical hydrophones, with each of the hydrophones separated by a periodic refractive index perturbation. In one aspect, the periodic refractive index perturbation is a Bragg grating; in another aspect, the periodic refractive index perturbation is a long period grating.

In another aspect, the present invention may include a layer of tape disposed around the acoustic substrate under the optical fiber which may have a low coefficient of friction relative to a coefficient of friction of the fiber. The tape may be formed from Teflon or the like.

In still another aspect, the present invention may include a filler rod inter-wound on the acoustic substrate with the optical fiber such that the filler rod is disposed approximately parallel to the optical fiber . In one aspect the filler rod may be formed of nylon. In another aspect, the filler rod has a diameter equal to or larger than a diameter of the optical fiber. In yet another aspect, the filler rod and optical fiber are inter-wound around the acoustic substrate so that there is a space between adjacent turns of the wound optical fiber, the space being filled with a compliant material, such as a thermoplastic elastomer or depolymerized rubber.

In a further aspect, the present invention may include a tape layer disposed around the inter-wound filler rod and optical fiber. In one aspect, the tape layer is formed from a material having a low coefficient of friction relative to the optical fiber, such as Teflon or polyimide polymer.

Another aspect of the present invention an external layer formed from an elastomer, which may be void filled. In another aspect, the present invention may include an outer tube in which the flexible core and optical fiber are disposed, there also being a space between the outer tube and the flexible core and optical fiber; and a material disposed within the space, the material for coupling acoustic signals from the outer tube to the flexible core and optical fiber. In one aspect, the material is a fluid, such as Isopar or Norpar (ExxonMobil Chemical Co.); in another aspect, the material is a low shear modulus polymer.

In a still further aspect, the present invention may include an outer elastomeric layer disposed on the flexible core and optical fiber, the elastomeric layer including hollow microspheres dispersed through the elastomeric layer to adjust buoyancy.

Other features and advantages of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, which illustrate, by way of example, the features of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1A is a perspective view of one embodiment of the present invention depicting an array of fiber optic acoustic sensors mounted on a flexible sub-core assembly and encased in a protective sheath.

FIG. 1B is a cross-sectional view of the embodiment of the present invention depicted in FIG. 1A.

FIG. 2 is an enlarged perspective view of a portion of the embodiment of FIG. 1 illustrating the spacing of fiber optic hydrophone elements wound upon the flexible sub-core assembly.

FIG. 2A is an enlarged perspective view of a portion of the embodiment of FIG. 1 illustrating the spacing of fiber optic hydrophone elements wound upon the flexible sub-core assembly and showing the use of a ring of low shear or high loss material disposed between adjacent windings of the fiber optic to decouple mechanical motion between the windings.

FIG. 3 is a perspective view, partially in cross-section, of an embodiment of the present invention where the hydrophone array is disposed within a fluid filled outer protective covering.

FIG. 4 is a perspective view, partially in cross-section, of another embodiment of the present invention where the hydrophone array is disposed within an outer protective covering and where the space between the hydrophone array and the outer covering is filled with a low shear solid material.

FIG. is a schematic view illustrating deployment of a hydrophone array in accordance with one embodiment of the present invention down a well bore.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the exemplary drawings, which illustrate, by way of example only, embodiments of the present invention, the present invention is generally embodied in a structure and method for forming that structure that includes a relatively flexible core through which extends an optical fiber. A series of reinforcing and protection layers are further would around the core , one layer of which includes windings of an optical fiber in which are formed one or more gratings, such as long period or Bragg gratings. The entire structure may further be surrounded by an outer jacket. In some embodiments, the resulting cable-line structure may be extended through a protective cylinder formed from a material such as glass, metal, polymer or other material as needed to provide additional protection to the sensor of the present invention depending upon the environment in which the sensor is to be deployed.

Figure 1 is an overall view of one embodiment of a solid fiber optic hydrophone array 10 in accordance with the present invention. A core sub-assembly 18 is formed using various layers of materials as described below, and then wrapping an optical fiber 17 around the core sub-assembly.

In the embodiment depicted in Figure 1, the core sub-assembly, starting from the innermost portion of the core, includes a durable hollow tube 11. This hollow tube may be formed from thin-walled metal tubing, such as, for example, but not limited to, 316 stainless steel, or other relatively flexible material suitable for use in the environment in which the hydrophone is to be deployed. The hollow tube 11 provides a space that extends throughout the entire length of the hydrophone or hydrophone array that may be used to house additional optical fibers 12, wires, or other communications means, that may be needed to send or receive signals from sensors or other equipment located downstream of the hydrophone or hydrophone array. Such a provision allows for a number of hydrophone arrays to be deployed using the same basic cable-like structure.

Hollow tube 11 my be surrounded by an intermediate elastomeric layer 13. This intermediate elastomeric layer may provide protection to the hollow tube, and may also act as an adhesive layer to aid in forming and attaching additional layers to the hollow tube 11. Typical materials that may be used are, for example, polyurethane and polyethylene.

Surrounding the elastomeric adhesive layer 13 is a strength member 14 made of metal wires or synthetic or natural fibers. For example, in one embodiment, the strength member layer 14 may be formed by closely winding a dense layer of synthetic fibers such as, for example, aramid fibers or Vectran, a product of Celanese Acetate LLC. The strength member limits the tensile strain transmitted to the hydrophone array structures during manufacture and deployment of the array to prevent failure of the assembly under the tensile strain forces experienced during deployment, retrieval and operational loading of the array assembly. It will be understood by those skilled in the art that other high strength natural or synthetic fibers may be used, depending on the design and operational specifications desired for a particular application. Moreover, in an embodiment of the present invention, electrical wires, such as twisted pairs of wires, may be wound around the hollow tube 11 before strength member 14 is added to the core sub-assembly.

The strength member 14 may be surrounded by an elastomer layer 15. Elastomer layer 15 encapsulates the inner layers of the core sub-assembly and also provides for maintenance of the radial uniformity of the strength member 14 and also may also provide a means for damping and isolating the hydrophone from vibration transmitted along the strength member 14. In some embodiments, elastomer layer 15 is surrounded by a layer 16 formed from a solid compressible material such as an elastomer. In one embodiment, the elastomer forming layer 16 may be a polyurethane or silicone rubber. In another embodiment, voids may be formed introduced within the solid compressible material with a material such as, for example, Expancel (Azko Nobel) closed cell polyethylene foam and the like.

Once layers 13, 14, 15 and 16 have been formed around hollow tube 11, the resulting core sub-assembly 18 is in the form of a long, continuous, flexible cylinder, which serves as the mounting base for the optical sensor fiber 17. Using methods known in the art, such as winding with a standard cable manufacturing taping head, the optical sensor fiber 17 is wrapped under a selected amount of tension, on the order of 100 grams, onto core sub-assembly 18 such that it remains under tension under all expected operating conditions of the hydrophone. Wrapping the fiber optic sensor 17 around core sub-assembly 18 in this manner ensures that an acoustic wave impacting the sensor will uniformly strain the optical sensing fiber. As shown in Fig. 2, fiber Bragg gratings, or long period gratings, may be incorporated into the optical sensor fiber 17 at appropriate intervals to form one or more acoustic sensors along the length of the hydrophone assembly.

As is known in the art, fiber Bragg gratings may be incorporated into an optical fiber using a variety of methods. One such method, for example, is described in U.S. Patent No. 6,222,973, Fabrication of Refractive Index Patterns in

Optical Fibers having Protective Optical Coatings, issued April 24, 2001, the subject matter of which is incorporated herein by reference in its entirety.

Once the optical fiber 17 has been wound on the core sub-assembly, an adhesive may be applied to hold the optical fiber in position on the core sub-assembly. The adhesive may also be applied during the winding process. Prior to winding the optical fiber 17 onto the core sub-assembly 18, the core sub-assembly 18 may be wrapped or coated with a layer 19 of material, which may be in the form of a tape, such as, for example, but not limited to, Teflon (DuPont de Nemours Co.), polyimide or other suitable material, having a low coefficient of friction with respect to the jacket of the optical fiber 17. The addition of low friction layer 19 ensures that optical fiber 17 can move with respect to overlying layers during bending of the hydrophone 10, reducing or eliminating the introduction of longitudinal strain onto the optical fiber 17 that may result in tensile failure of optical fiber 17.

The optical fiber 17, including any gratings formed therein, may be uncoated, or it may be coated prior to winding with a metallic or non-metallic materials, depending on the needs of the particular application in which the hydrophone is to be used. Where a coating is applied, the optical fiber may be coating using known processes, such as pressure or tubing extrusion. Coating the optical fiber 17 prior to winding typically improves the acoustic sensitivity of the resultant sensor.

In an embodiment of the present invention where the optical fiber 17 is coated with a solid elastomer, or an elastomer that has been modified to include voids dispersed within the elastomer coating, the acoustic substrate of the hydrophone, layer 16, may be formed from a stiffer material than would otherwise be appropriate. For example, layer 16 may be formed from a polymer having a relatively higher elastic modulus of, for example, on the order of 80 or greater Shore A hardness, such as a suitable silicone polymer, or an incompressible polymer such as, for example, unfilled polyurethane or polyethylene. Forming layer 16 from such a material may be advantageous where reduced sensitivity of the fiber optic sensors is required, such as to hydrostatic pressures caused by deep deployment of the sensors in water, such as in the ocean, or in oil or gas wells.

The optical fiber 17 may be wound in parallel with a radial support rod 20. Radial support rod 20 may be made of a plastic material such as nylon, or other suitable material, and protects optical sensor fiber 17 during subsequent handling, including deployment, reeling and extrusion. Additionally, the interstitial volume between the optical fiber 17 and the radial support rod 20 may be filled with a low modulus material 21 such as a thermoplastic elastomer of the type typically used during standard cable manufacture to block diffusion of water into the cable structure, or, alternatively, with a material such as depolymerized rubber. Low modulus material layer 21 provides support for any subsequent tape and/or extruded protective layers, as well providing as isolation from external shear stresses on the hydrophone 10 that occur during or operation of the hydrophone 10.

In one embodiment of the present invention, a layer 22 formed from a material, such as Teflon, polyimide or the like, having a lower coefficient of friction than the jacket of the optical fiber 17 may be applied over low modulus material layer 21 to ensure radial consistency of the low modulus material 21. Layer 22 may be wound on the assembly as a layer of tape. Layer 22 is surrounded by a layer 23 formed from a low shear strength elastomer, such as, for example, polyurethane and silicone rubber and the like having a hardness on the order of approximately 30-40 on the Shore A scale. Acting as a noise reduction mechanism, layer 23 isolates the optical fiber 17 from longitudinally applied shear stresses that contribute to acoustic noise within the hydrophone.

The final layer applied to the hydrophone assembly is typically a tough elastomeric outer jacket 24. The outer jacket 24 protects the hydrophone 10 from mechanical handling, abrasion, deployment and operational stresses. Outer jacket 24 may be formed from a variety of suitable materials including, for example, polyurethane, polyethylene, nitrile rubber, or other materials having the desired physical characteristics.

While an embodiment of the present invention has been described as being surrounded by outer jacket 24, in other embodiments, the outer jacket 24, and layers 21, 22 and 23 may be omitted. However, such embodiments will likely need to be disposed within a fluid filled or solid filled tube to protect the hydrophone from damage, as is typical in presently available towed hydrophone arrays.

Figure 2 illustrates the details of a hydrophone array 30 including a plurality of hydrophones 55 formed in accordance with the embodiment of the present invention described above. In this embodiment of the present invention, the plurality of hydrophones may be formed on a continuous core sub-assembly 31. Prior to winding, one or more fiber Bragg gratings 32 are written into an optical fiber 17 (Fig. 1) at predetermined intervals. This predetermined interval between gratings 32 (Fig. 2) becomes the hydrophone length 33, and may vary depending on the type and wavelength of the signals to be sensed, as well as the sensitivity and imaging capabilities desired. The length of optical fiber between each fiber Bragg grating is an individual sensing element 55. The optical fiber 17 is wound around core sub-assembly 31 at a pitch selected to maintain the required hydrophone acoustic sensitivity and spacing 33 based upon acoustic requirements.

Adjacent hydrophones in accordance with the present invention may be bound by gratings having different center wavelengths. For example, in one embodiment, a first hydrophone section is bounded by a grating having a first center wavelength and a second hydrophone section is bounded by a grating having a second, different center wavelength. An array of this type provides for wavelength division multiplexing, as the signals from both arrays will capable of separation and analysis using signal processing techniques well known in the art.

One potential problem is the occurrence of mechanical motion between adjacent sensors that may reduce the sensitivity of the array. Mechanical coupling of this kind may be reduced, or eliminated, by adding a thin layer of low shear material, such as, for example, polyurethane or the like having a Shore A hardness of approximately 30-40, between layer 15 and the acoustic substrate formed by layer 16. In an alternative embodiment, decoupling mechanical motion between adjacent sensors may be accomplished by substituting rings of low shear or high loss material 25, such as for example, polyurethane or the like having a Shore A hardness of approximately 30-40, in place of the acoustic substrate formed by layer 16 in segments between adjacent sensors, as shown in shown in Fig. 2A.

Figure 3 illustrates an alternative embodiment of the present invention depicting a hydrophone 60 formed in accordance with the description above, but omitting the outer layers of the hydrophone assembly surrounding the optical fiber 17. In this embodiment, the hydrophone 60 is installed within a liquid-filled hydrophone array of the type commonly used in towed arrays. Hydrophone 60, which may also include outer layers and protective covering 24, is installed within a tube 70 that is filled with a liquid 65, such as, for example, Isopar or Norpar (ExxonMobil Chemical Company), or other suitable fluid. Tube 70 serves to protect the hydrophone 60, while the fluid 65 acoustically couples the hydrophone to the exterior cases to reduce, to the extent possible, attenuation of acoustic signals transferred from the exterior of tube 70 to the hydrophone 60, and decouples shear stress between the tube 70 and the hydrophone 60.

Figure 4 illustrates yet another embodiment of the present invention depicting a hydrophone 80 formed in accordance with the description above, but omitting the outer layers of the hydrophone assembly surrounding the optical fiber 17, although there is no requirement to remove the outer layers, and the device would function acceptably if the outer layers were in place. In this embodiment, the hydrophone 80 is installed within a hydrophone array having an outer jacket 90. Hydrophone 80 is installed within a tube 90, designed to protect the hydrophone, that is filled with a low shear strength solid fill material 85 such as a polymer which may also include voids dispersed throughout the polymer to improve acoustic coupling of acoustical signals to the hydrophone 80 to reduce, to the extent possible, attenuation of acoustic signals transferred from the exterior of tube 90 to the hydrophone 80 while decoupling shear stress between the tube 90 and the hydrophone 80.

Figure 5 illustrates one application utilizing a hydrophone array in accordance with present invention deployed in a bore hole. A borehole hydrophone array 100 in accordance with the present invention may be deployed in an oil or gas well 105, or any other bore hole such as a geothermal well. A lead cable 110 incorporating a fiber optic for transmitting signals to and from the array 100 is used to lower the array 100 using deployment apparatus 115 into the well. Lead cable 110 is connected to an acoustic receiver 120, which may contain all of the electronics and optical components necessary to provide a light beam down the optic fiber and into the array 100, and also to analyze the phase shifts in the signals returning from the array and to convert those signals into a form representative of the received acoustic signals that may be displayed, printed or further analyzed. Additionally, interrogator 120 may configured to communicate with additional processing equipment, such as a computer or computer network. The communications may occur either over wires or other hard connections, including optical networks, or the communications may occur wirelessly.

It will be apparent to those skilled in the art that the core sub-assembly and outer layers can be manufactured in continuous, one piece, homogeneous sections, using standard cable manufacturing techniques, such as extrusion and winding. These sections of the core sub-assembly can be wound with a continuous optical fiber to create hydrophone arrays, with fiber Bragg gratings spaced at appropriate intervals to provide the desired sensor spacing. These continuous, one piece sections containing the arrays may be wound upon commonly available spools and deployed using deployment equipment commonly available. The novel features of the present invention thus provide a system and method for providing easily deployable arrays of hydrophones or geophones that are rugged and capable of withstanding harsh environments.

While several particular forms of the invention have been illustrated and described, it will be apparent that various modifications can be made without departing from the spirit and scope of the invention.

WHAT IS CLAIMED IS:

1. A continuous, flexible cylindrical device for detecting acoustic signals, comprising:

a flexible core including an acoustic substrate;

an optical fiber wound around the acoustic substrate; and

at least one periodic refractive index perturbation formed in the optical fiber.

2. The device of claim 1, wherein the acoustic substrate contains a plurality of voids.

3. The device of claim 2, wherein the voids are formed by hollow microspheres.

4. The device of claim 3, wherein the microspheres are formed from a compliant material.

5. The device of claim 1, wherein the flexible core includes a hollow tube for providing a passageway through the core.

6. The device of claim 1, wherein the flexible core includes a strength member for providing tensile strength to the core to resist stretching or breaking of the core during deployment, retrieval or use.

7. The device of claim 5, wherein the flexible core includes a strength member surrounding the hollow tube for providing tensile strength to the core to resist stretching or breaking of the core during deployment, retrieval or use.

8. The device of claim 7, further comprising an intermediate jacket disposed between the metal tube and the central strength member.

9. The device of claim 6, further comprising a jacket disposed over the strength member.

10. The device of claim 8, further comprising a jacket disposed over the strength member.

11. The device of claim 1, wherein the acoustic substrate includes a an elastomeric material having a selected dynamic property for limiting the sensor frequency response to within a desired range of frequencies.

12. The device of claim 1, wherein the optical fiber is wound under tension to form at least one optical hydrophone.

13. The device of claim 12, wherein the optical fiber is wound under tension to form a plurality of optical hydrophones, with each of the hydrophones separated by a periodic refractive index perturbation.

14. The device of claim 13, wherein the periodic refractive index perturbation is a Bragg grating.

15. The device of claim 13, wherein the periodic refractive index perturbation is a long period grating.

16. The device of claim 1, further comprising a layer of tape disposed around the acoustic substrate under the optical fiber.

17. The device of claim 16, wherein the tape has a low coefficient of friction relative to a coefficient of friction of the fiber.

18. The device of claim 16, wherein the tape is formed from Teflon.

19. The device of claim 1, further comprising a filler rod, the filler rod inter-wound on the acoustic substrate with the optical fiber such that the filler rod is disposed approximately parallel to the optical fiber .

20. The device of claim 19, wherein the filler rod is formed from nylon.

21. The device of claim 19, wherein the filler rod has a diameter equal to or larger than a diameter of the optical fiber.

22. The device of claim 21, wherein the filler rod and optical fiber are inter-wound around the acoustic substrate so that there is a space between adjacent turns of the wound optical fiber, the space being filled with a compliant material.

23. The device of claim 22, wherein the compliant material is a thermoplastic elastomer.

24. The device of claim 22, wherein the compliant material is depolymerized rubber.

25. The device of claim 23, further comprising a tape layer disposed around the inter-wound filler rod and optical fiber.

26. The device of claim 25, wherein the tape layer is formed from a material having a low coefficient of friction relative to a coefficient of friction of the optical fiber.

27. The device of claim 26, wherein the material is Teflon.

28. The device of claim 26, wherein the material is a polyimide polymer.

29. The device of claim 1, wherein the optical fiber includes an external layer formed from an elastomer.

30. The device of claim 29, wherein the elastomer is void filled.

31. The device of claim 1, further comprising:

an outer tube in which the flexible core and optical fiber are disposed, there also being a space between the outer tube and the flexible core and optical fiber; and

a material disposed within the space, the material for coupling acoustic signals from the outer tube to the flexible core and optical fiber.

32. The device of claim 31, wherein the material is a fluid.

33. The device of claim 31, wherein the material is a low shear modulus polymer.

34. The device of claim 32, wherein the fluid is Isopar.

35. The device of claim 32, wherein the fluid is Norpar.

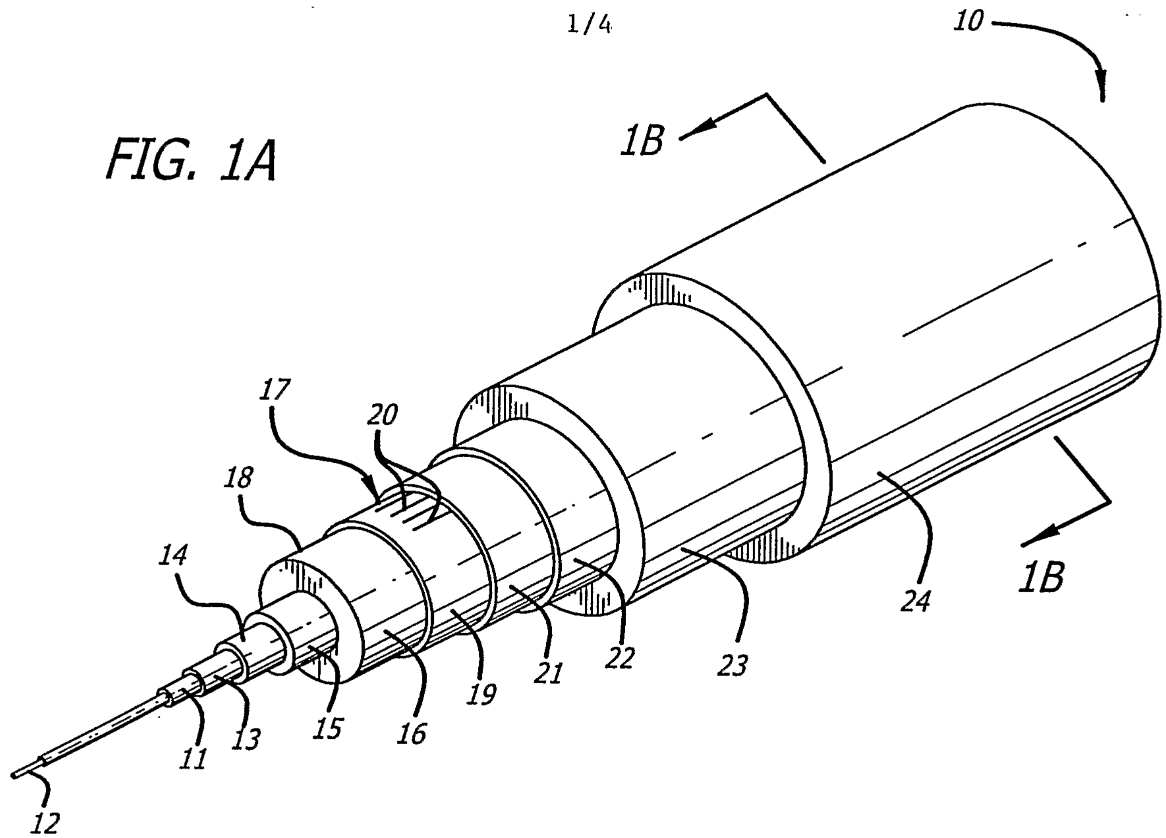
36. The device of claim 31, further comprising an outer elastomeric layer disposed on the flexible core and optical fiber, the elastomeric layer including hollow microspheres dispersed through the elastomeric layer to adjust buoyancy.

37. The device of claim 31, wherein the material is an elastomeric material having a plurality of microspheres dispersed throughout the elastomeric material for providing pressure-compensated structural support for the flexible core and optical fiber.

38. The device of claim 13, further comprising a ring of low shear material disposed between at least one pair of adjacent optical hydrophones.

39. The device of claim 3, wherein the microspheres are formed from Expancel.

FIG. 1A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1B
1B
17
20
18
14
24
22
23
21
19
16
15
13
11
12

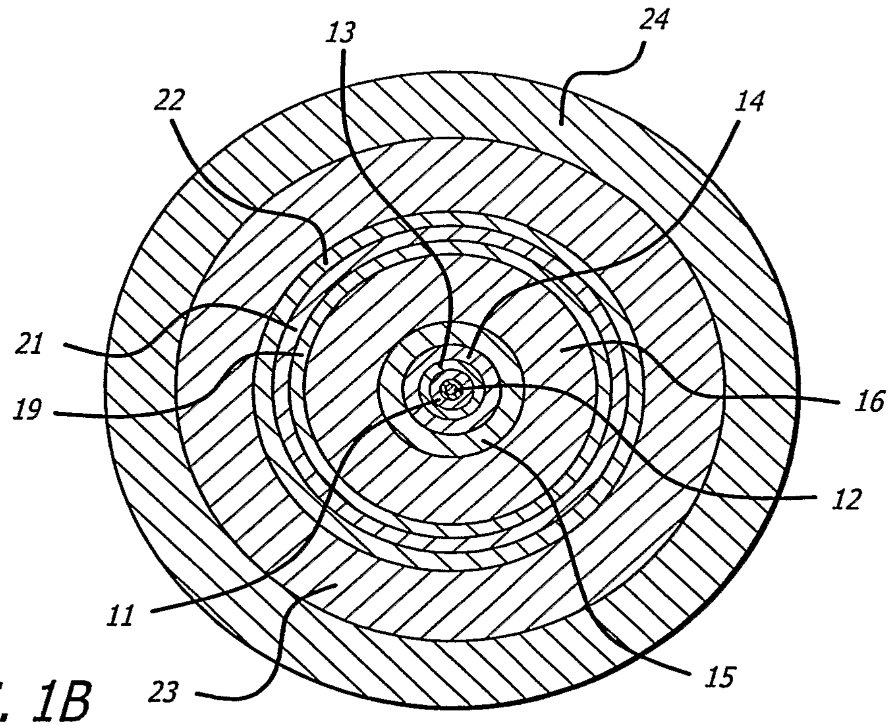
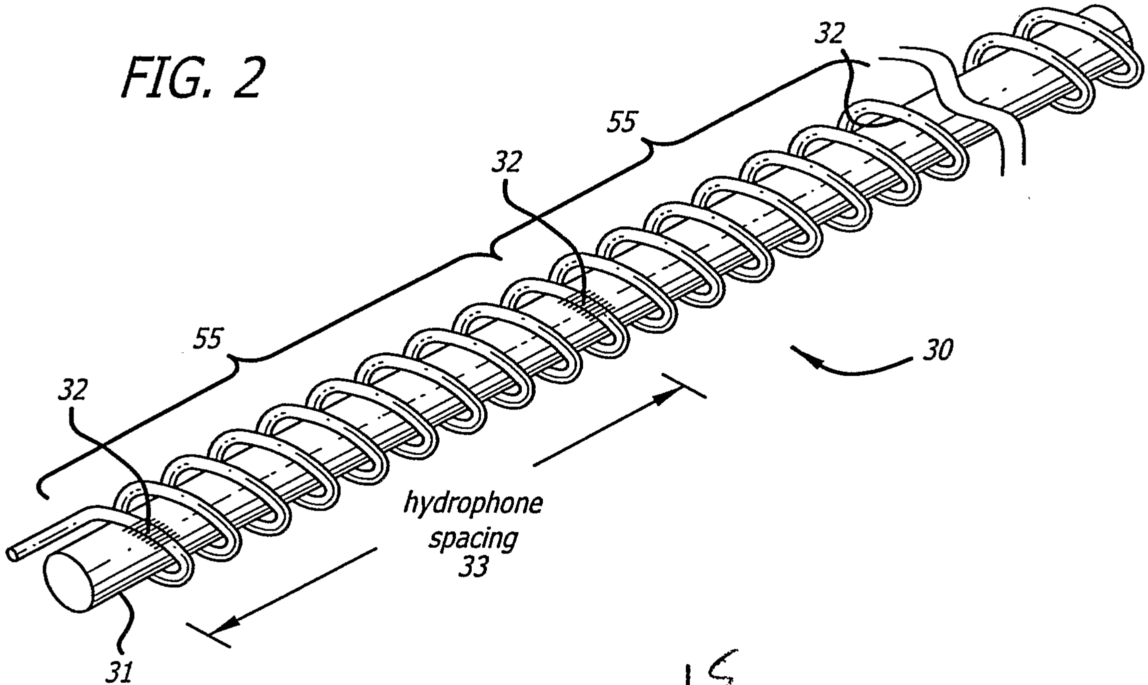

13
24
22
14
21
19
16
12
11
23
15

FIG. 1B

FIG. 2



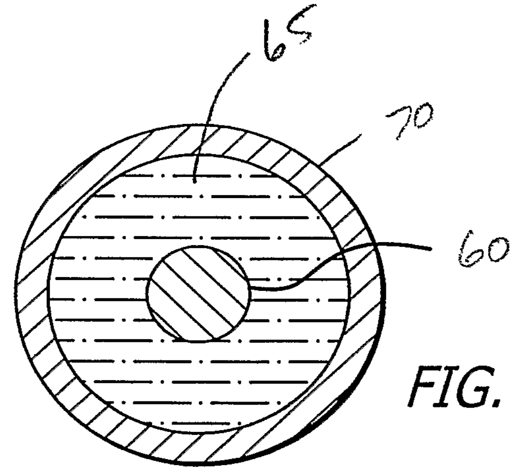


FIG. 3

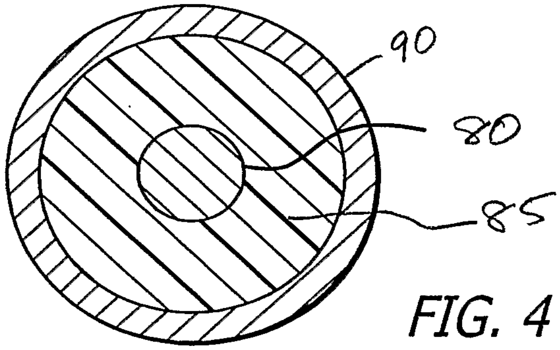


FIG. 4

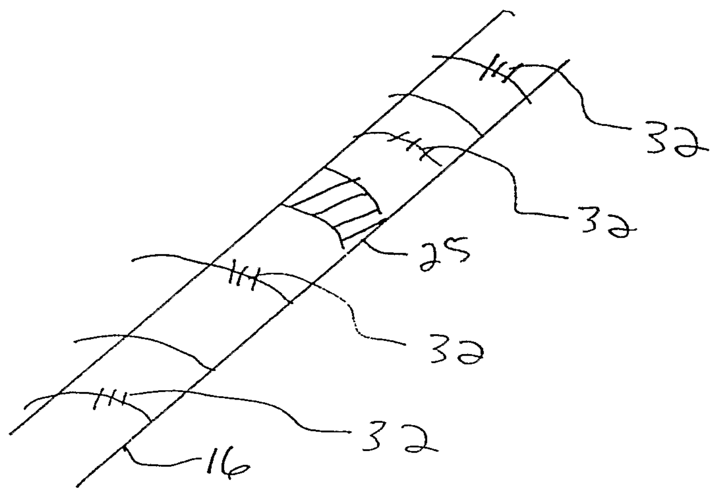


FIG. 2A

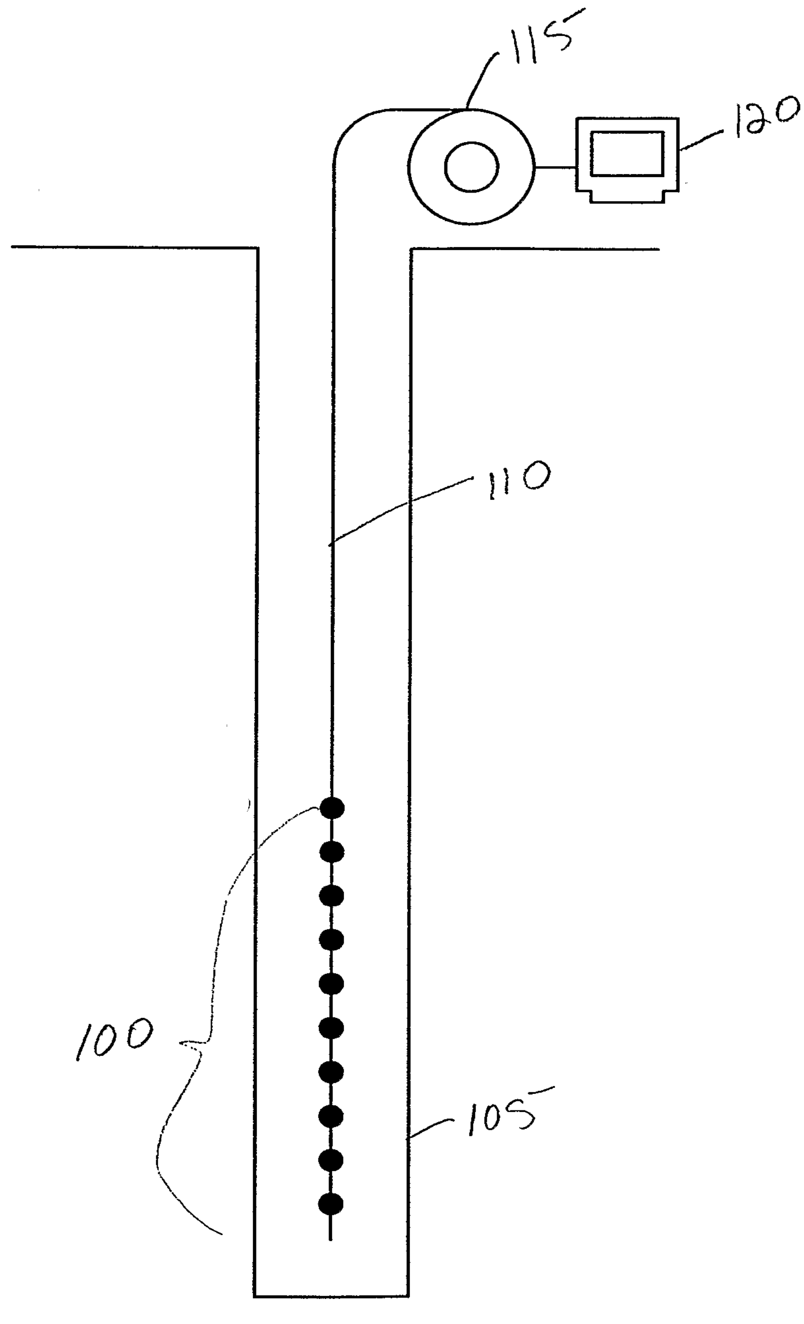


FIG. 5

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H4B BKX

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(54) Abstract Title
Optical waveguide Bragg grating system

(57) An optical waveguide Bragg grating system has a length of optical waveguide 2 containing a set of Bragg gratings at each of a number of locations 10, 20, 30. Each location is assigned a unique digital code defining the wavelength set of the gratings at that location. The Bragg grating locations may be mechanical-strain sensing locations. For sensing, the waveguide 2 is coupled to a broadband optical source 5 and the combined response from all the grating locations 15 is correlated 16 with each digital code to discriminate responses from the respective grating locations. In an alternative arrangement, a communication system uses a plurality of sources of unique wavelength and reflective taps at each grating location.

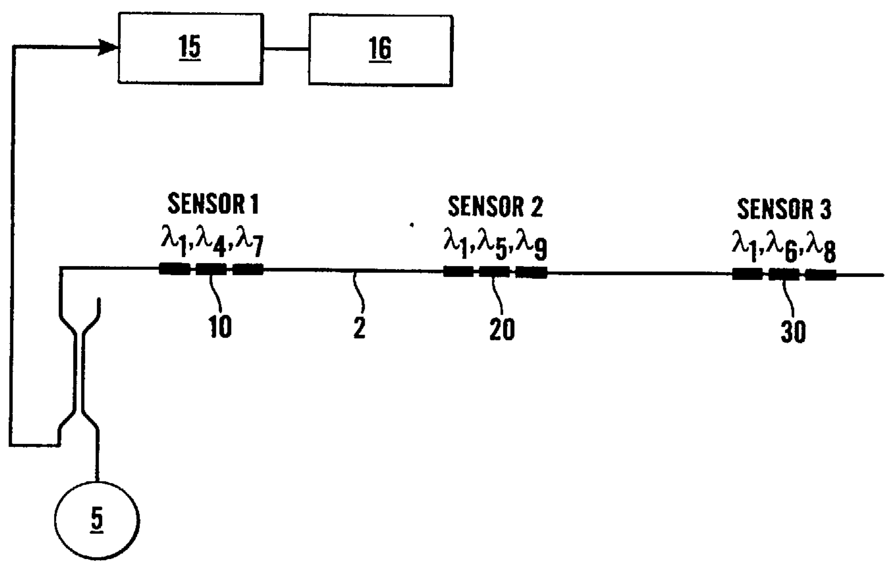

Fig. 1(b)

GB 2 372 100 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

The print reflects an assignment of the application under the provisions of Section 30 of the Patents Act 1977.

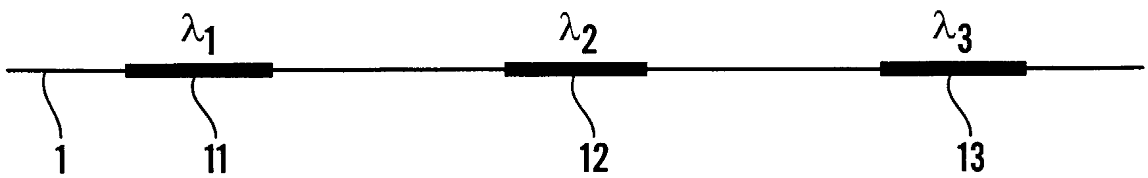
λ_1
λ_2
λ_3
1
11
12
13

Fig. 1(a)

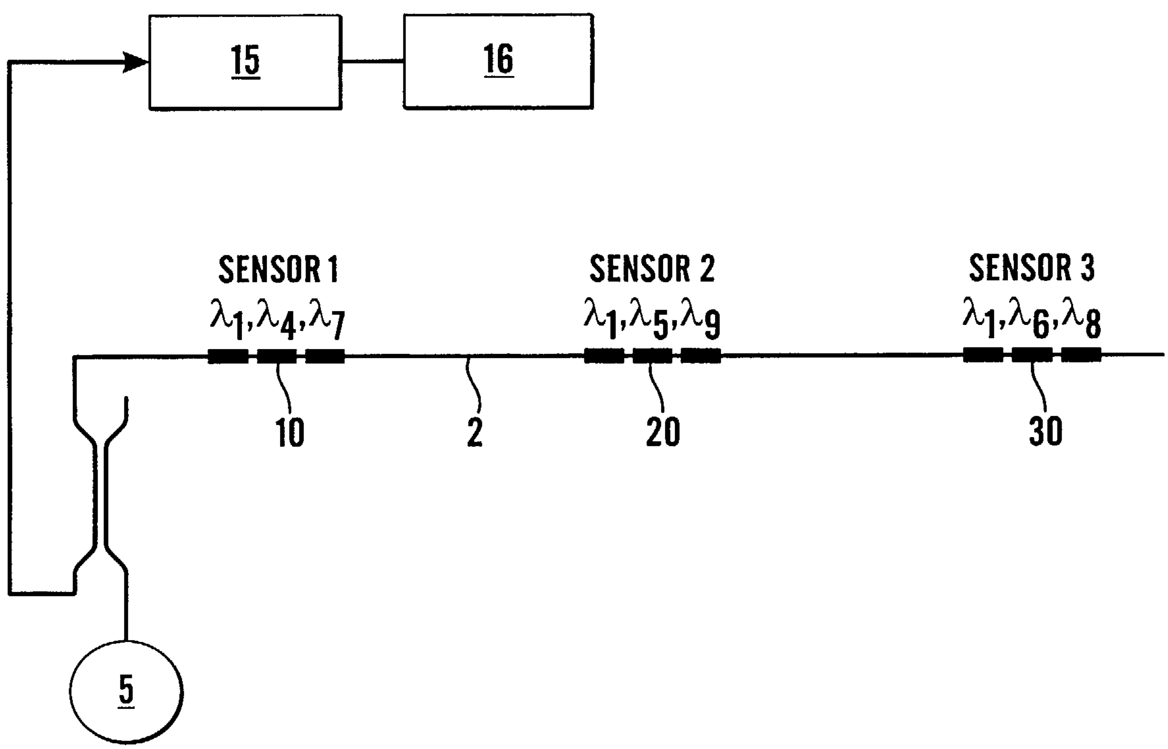
15
16
SENSOR 1
$\lambda_1,\lambda_4,\lambda_7$
SENSOR 2
$\lambda_1,\lambda_5,\lambda_9$
SENSOR 3
$\lambda_1,\lambda_6,\lambda_8$
10
2
20
30
5

Fig. 1(b)

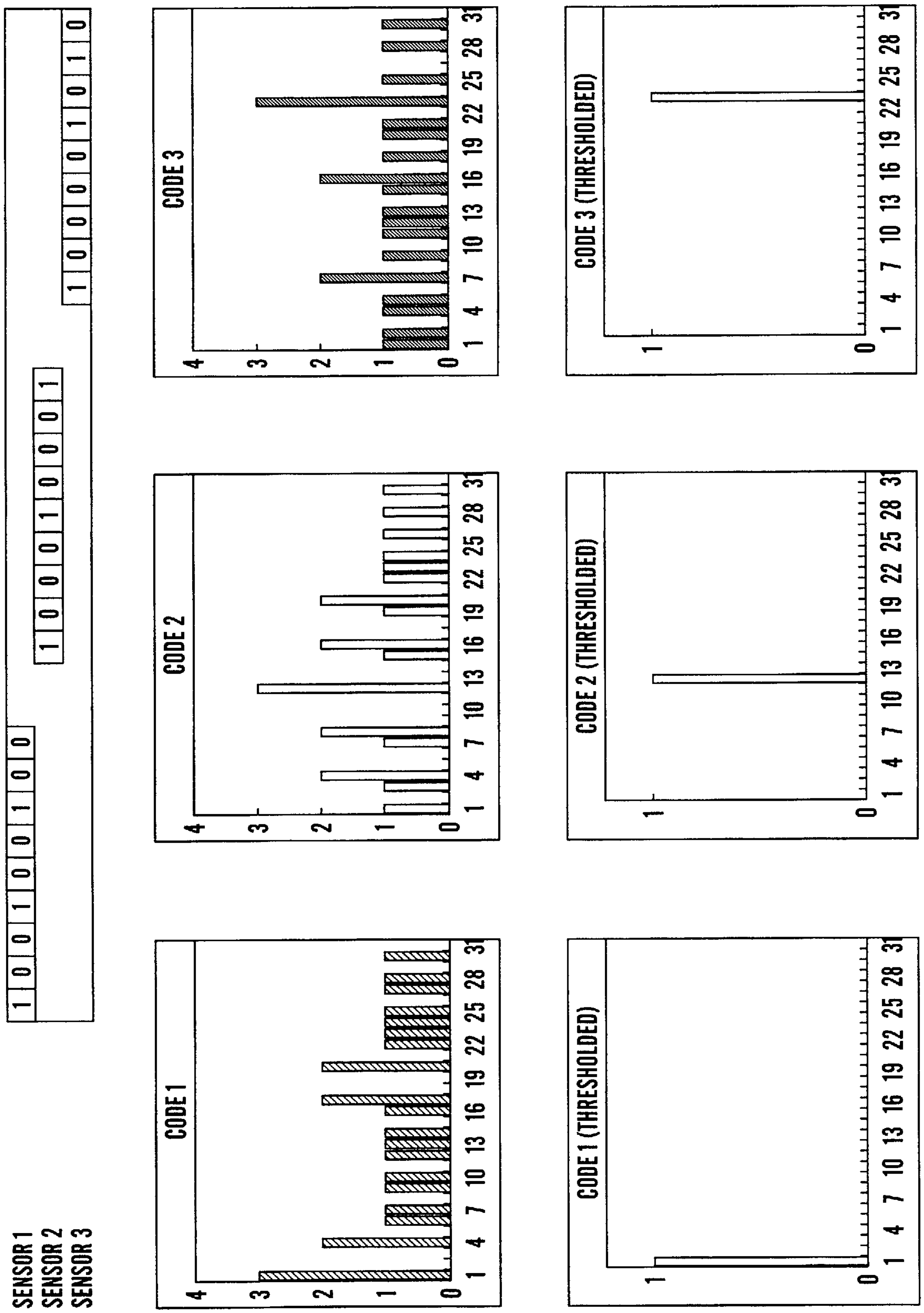
SENSOR 1
SENSOR 2
SENSOR 3
CODE 1
CODE 2
CODE 3
CODE 1 (THRESHOLDED)
CODE 2 (THRESHOLDED)
CODE 3 (THRESHOLDED)

Fig.2

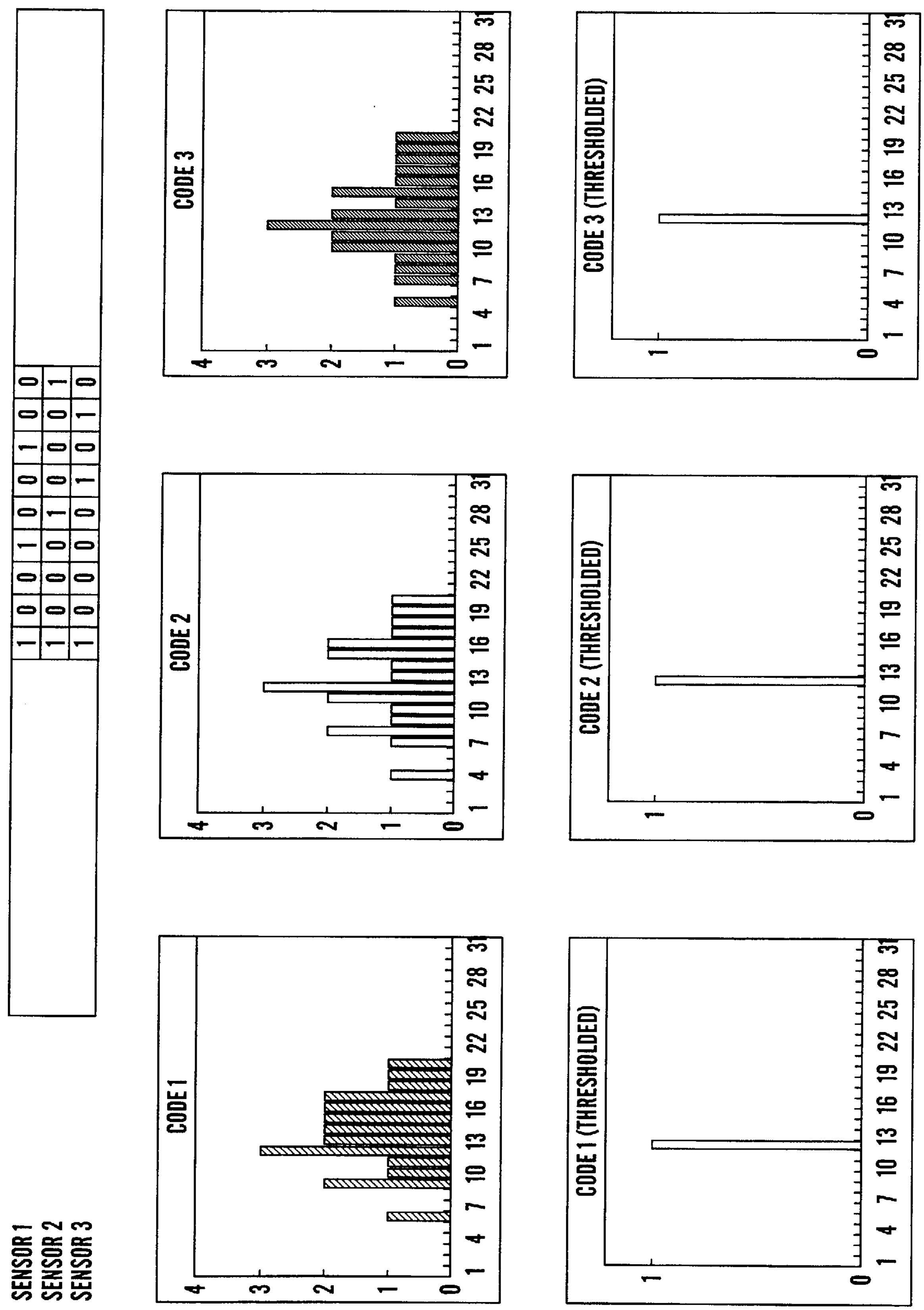
SENSOR 1
SENSOR 2
SENSOR 3
1 0 0 1 0 0 1 0 0
1 0 0 0 1 0 0 0 1
1 0 0 0 0 1 0 1 0
CODE 1
CODE 2
CODE 3
CODE 1 (THRESHOLDED)
CODE 2 (THRESHOLDED)
CODE 3 (THRESHOLDED)

Fig.3

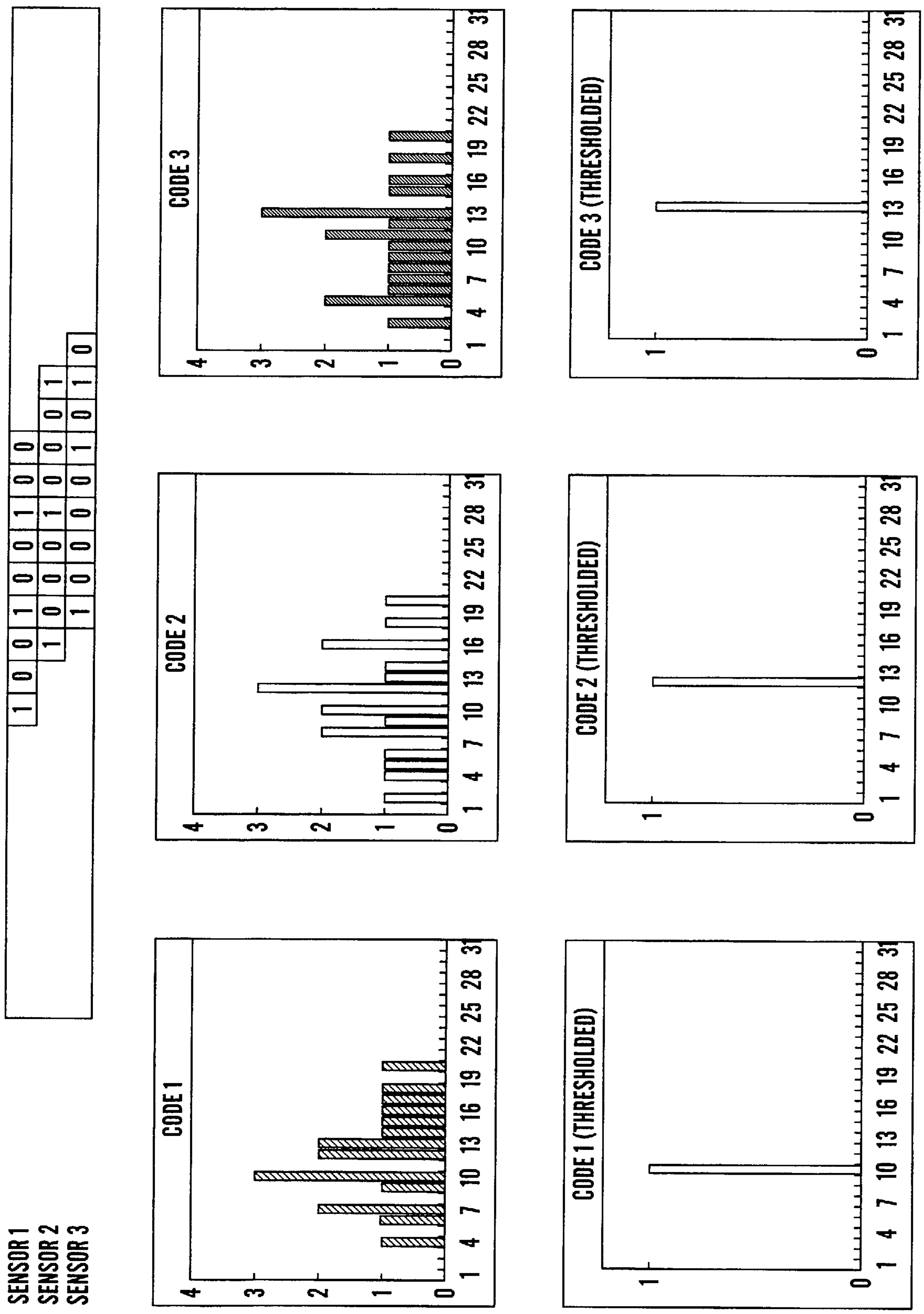
SENSOR 1
SENSOR 2
SENSOR 3
CODE 1
CODE 2
CODE 3
CODE 1 (THRESHOLDED)
CODE 2 (THRESHOLDED)
CODE 3 (THRESHOLDED)

Fig.4

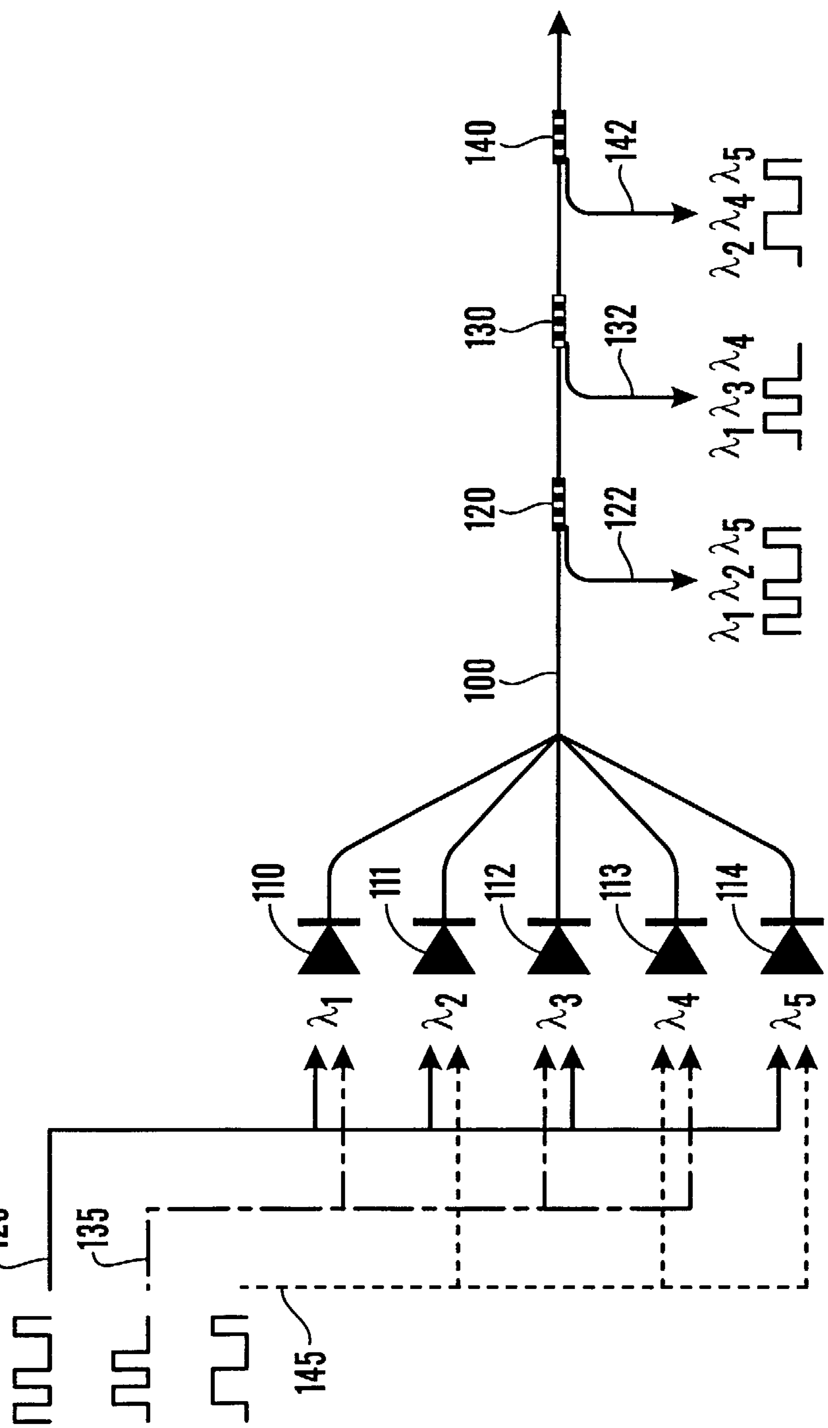
125
135
145
λ1
λ2
λ3
λ4
λ5
110
111
112
113
114
100
120
122
130
132
140
142
λ1 λ2 λ5
λ1 λ3 λ4
λ2 λ4 λ5

Fig.5

OPTICAL WAVEGUIDE BRAGG GRATING SYSTEM

This invention relates to an optical waveguide Bragg grating system and particularly, although not exclusively to a system utilising optical fibre Bragg gratings as sensors.

Optical waveguide Bragg gratings are finding increasing application as sensors, particularly of mechanical strain and other parameters, for example temperature, which can be represented in terms of induced strain.

A plurality of Bragg gratings can usefully be cascaded along the length of a single waveguide such as an optical fibre. In sensor applications, this usefully provides the ability to sense a parameter at the location of each grating in the series. In such an arrangement each sensor in the series has a unique wavelength response and the sensors are addressed by means of a single wideband optical source, the bandwidth of which covers the wavelength response range of all the sensors in a series. Analysing the reflected response from all the sensors by means of a spectrum analyser enables the responses from individual sensors to be determined.

A cascaded Bragg grating system as described, has a significant limitation in the form of the inevitable compromise, which has to be made between the number of gratings in the series, their required dynamic range and the optical bandwidth available from a single optical source.

This invention seeks to provide an optical waveguide Bragg grating system in which the above-mentioned limitation is mitigated.

According to one aspect of the invention there is provided an optical waveguide Bragg grating system comprising a length of optical waveguide having a plurality of Bragg grating locations spaced apart along its length, each grating location containing a plurality of superimposed Bragg gratings formed thereat, each of the superimposed gratings at a respective location having a characteristic response wavelength different from the other gratings at that location, each location being assigned a unique digital code defining a unique set of response wavelengths of the gratings at that location, an optical source for providing an optical signal to the optical waveguide, the signal having a bandwidth which includes the response wavelength of each grating at each location, a correlator for correlating in wavelength space combined optical responses from all locations with each code, whereby the responses from each grating location may be uniquely determined.

The optical waveguide is preferably an optical fibre, typically single mode optical fibre.

A signal amplitude threshold circuit may be coupled to an output of the correlator to increase discrimination of the responses from the respective grating locations.

The digital codes assigned to the grating locations may be Prime Codes.

The Bragg grating locations may be mechanical strain-sensing locations, a change in the wavelength response from a respective location being indicative of a change in mechanical strain induced in the optical waveguide at that location.

According to a second aspect of the invention there is provided an optical Code Division Multiple Access (CDMA) data communications system comprising a length of optical fibre waveguide having a plurality of Bragg grating locations spaced apart along its length, each grating location containing a plurality of superimposed Bragg gratings formed thereat, each of the superimposed gratings at a respective location having a characteristic response wavelength different from the other gratings at that location, each location being assigned a unique digital code defining a unique set of response wavelengths of the gratings at that location and having a respective reflective tap, a plurality of optical sources coupled to the optical waveguide, each source having a unique respective wavelength corresponding to the characteristic response wavelength of a different respective one of the gratings at the plurality of Bragg grating locations, a data input for feeding data intended to be received at the reflective tap of a grating location to each optical source having a wavelength corresponding to the characteristic response wavelength of each grating at said grating location and a correlator coupled to each reflective tap for correlating in wavelength space optical signals received at a respective tap with each digital code, whereby data signals intended for that tap may be discriminated.

The optical waveguide is preferably an optical fibre, typically single mode optical fibre.

A signal amplitude threshold circuit may be coupled to an output of each correlator to increase discrimination of the responses from the respective grating locations.

The digital codes assigned to the grating locations may be Prime Codes.

An exemplary embodiment of the invention will now be described with reference to the drawings in which:

Fig.1 (a) shows a known Bragg grating system;

Fig. 1 (b) shows a preferred embodiment of a Bragg grating system in accordance with a first aspect of the invention;

Figs.2, 3 and 4 illustrate results of correlation for three possible cases; and

Fig.5 shows a preferred embodiment of an optical CDMA data communications system in accordance with a second aspect of the invention.

Referring now to Fig.1(a), there is shown a known optical waveguide Bragg grating system in which a single mode optical fibre 1, has Bragg gratings 11, 12, and 13 of respective characteristic reflection wavelengths λ_1, λ_2, λ_3 formed at intervals along its length. In this example the gratings are provided as sensors for sensing, for example mechanical strain.

The gratings 11, 12 and 13 are typically addressed by means of a wide-band optical source coupled to the fibre 1 and reflected responses from the grating sensors are analysed by means of a spectrum analyser. A change in the spectral response of a grating sensor indicates a change in the sensed parameter, in this case mechanical strain.

A problem with this arrangement is the compromise, which must be made between the number of grating sensors, which may be cascaded in this way, their required dynamic range and the optical bandwidth available from a single source, to cover the range of characteristic reflection wavelengths of all the cascaded gratings. In a typical strain sensing application, it is possible to support eight cascaded Bragg grating sensors, each having a wavelength window 5nm wide, equivalent to a strain-response range of 0-3000μstrain, within the typical 40nm spectral range of state-of-the-art semiconductor diode sources.

In seeking to mitigate this problem, the present invention draws on techniques from the field of Code Division Multiple Access, (CDMA) communications to provide resolution of the responses from optical waveguide Bragg gratings.

In a typical CDMA system, each bit is encoded into a waveform s(t) that corresponds to a code sequence of N chips representing the destination address of that bit. Each receiver correlates its own address $f(t)$ with the received signal $s(t)$. The received output $r(t)$ is:

$$r(t) = \int_{-\infty}^{\infty} s(z).f(z-t).dz \qquad (1)$$

If the signal has arrived at the correct destination, then $s(t) = f(t)$ and Equation (1) represents an auto-correlation function. If the signal has arrived at an incorrect destination, then $s(t) \neq f(t)$ and (1) represents a cross-correlation function. At each receiver, to maximise the discrimination between the correct (destination) signal and interference (all other signals), it is necessary to maximise the auto-correlation function and to minimise the cross-correlation function. This is accomplished by selecting a set of orthogonal code sequences. Optimum discrimination occurs for conditions under which the auto-correlation function is a maximum and the cross-correlation function is simultaneously a minimum. The size of the code applied to each transmitted bit depends on the number of receivers in the system. In a binary signalling scheme, this has a minimum size of 2^{N-1}, where N is the number of receivers involved, although optimum code design strategies may demand significantly longer codes.

In the present invention these principles are applied in a first aspect of the invention to discriminating responses from a set of Bragg grating locations spaced along a length of optical waveguide and in a second aspect to provide an optical CDMA data system in which data signals intended for respective ones of a number of locations may be discriminated by means of Bragg gratings provided at those locations.

Referring to Fig.1 (b), there is shown a Bragg grating sensor system comprising an optical waveguide in the form of a single mode optical fibre 2 provided with Bragg grating locations 10, 20, 30 at spaced intervals along its length. A wideband optical source 5 is coupled to feed the optical fibre 2 and signals reflected from each Bragg grating location 10, 20, 30 are fed to a spectrum analyser 15 and then to a correlator circuit 16.

Each Bragg grating location incorporates three gratings each having its own respective characteristic wavelength response, the set of three wavelengths at each grating location being unique to that location and hence different from the wavelength response set of any other grating location.

Each grating location 10, 20, 30 is assigned a digital code which defines in wavelength space the characteristic wavelength response of the three gratings at the respective location. Suitable code sequences are Prime Codes. These were initially developed as codes applicable to optical systems, giving better correlation properties in intensity-summation systems (i.e. in which the detected signal is always zero or positive) than the previous generation of codes (exemplified by Gold-sequences), which are more applicable to amplitude-detection. The following description is made with reference to Prime Codes, but the invention is not limited to such codes and any other suitable code sequence may be used.

For the system of Fig.1 (b), having three sensing sites, each with three gratings, the relevant Prime Codes are;

User	**Code Sequence**		
1	100	100	100
2	100	010	001
3	100	001	010

In this case Users 1, 2 and 3 represent the Bragg grating locations 10, 20, 30 and the code sequences represent the wavelengths of the characteristic wavelength responses of the three Bragg gratings at each location. Thus in a wavelength space covering nine different characteristic wavelengths of the code sequence, the gratings for user 1 at location 10 are assigned wavelengths λ_1, λ_4 and λ_7, those at grating location 20 wavelengths λ_1, λ_5 and λ_9 and those at location 30 wavelengths λ_1, λ_6 and λ_8.

As described, a multiplicity of sensors share a common wavelength space and the potential dynamic range, in wavelength terms, can therefore be much larger, since it is not necessary to prevent the dynamic wavelength excursions of one grating from encroaching on the spectral space allocated to its neighbours. In wavelength-space, therefore, the reflected response of a particular sensor comprises a number of delta-functions, forming a pattern unique to that sensor.

In order to discriminate the responses from the individual Bragg grating sensor locations, a spectral analysis is made of the sum of all grating sensor responses, taking no account of the positional origin of the signals received by the detection system consisting of the spectrum analyser 15 and the correlator 16. In the present example in which the Bragg gratings at the three locations are functioning as strain sensors, as an individual sensing location experiences strain (or responds to an influence inducing strain) its characteristic coded response pattern shifts across the spectrum, modifying the integrated detected spectrum.

By performing, in correlator 16, a correlation in wavelength-space of the integrated detected spectral pattern against the specific sensor code, it is possible to assign the sensor response a position, which directly represents the induced shift in the wavelength pattern associated with the specific sensor location. With suitable choice of code patterns, the cross-correlation of the detected pattern associated with any particular sensor against the codes of the remaining sensors in the set can be minimised, providing an unambiguous interrogation of any individual sensors in the set.

Referring now to Figs 2, 3 and 4 there are shown the output of the correlator 16 for three cases. The first line of each Figure shows the raw results of autocorrelation, while the second row shows the same results after subjecting to thresholding.

In Fig.2, the nine-bit codes for each of the three sensor locations occupy non-overlapping positions in a 32-bin wavelength space. In this case all sensor locations are completely resolved at positions 1, 12 and 23.

In Fig. 3, all three sensor locations are completely coincident in wavelength space, but as can be seen, the auto correlation with the respective codes discriminates each sensor response at position 12.

Similarly in Fig. 4, where sensor codes overlap in wavelength space, sensor outputs at positions 10, 12 and 13 are discriminated.

As can also be seen by thresholding the correlator output at signal magnitude slightly in excess of 2 on the vertical axis of each figure, the discrimination against unwanted signals is considerable enhanced.

The above example has been described with reference to a nine bit code suitable for three sensor locations. The size of the code can be increased with a corresponding increase in the number of grating/sensing locations which may be supported and enhanced discrimination between auto-correlation and cross-correlation functions.

The following is an example of the Prime codes for a five user/location system;

User	**Code Sequence**				
1	10000	10000	10000	10000	10000
2	10000	01000	00100	00010	00001
3	10000	00100	00001	01000	00010
4	10000	00010	01000	00001	00100
5	10000	00001	00010	00100	01000

The multiple Bragg gratings at each of the grating locations may be formed adjacent to each other, or to be superimposed one upon another. Such multiple gratings may be formed by known techniques for forming Bragg gratings in optical fibres, such as, holographic exposure, phase mask exposure or direct writing into the fibre by optical beam.

In a second aspect, the invention may usefully be applied to provide an optical data communications system. One exemplary embodiment is illustrated in Fig.5. In Fig. 5, an optical waveguide in the form of a single mode optical fibre 100 has coupled thereto five optical sources, typically laser diode sources, 110, 111, 112, 113 and 114, of respective wavelengths λ_1, λ_2, λ_3, λ_4, and λ_5.

At each of a plurality of locations, 120, 130 and 140 is provided a set of three Bragg gratings, those at location 120 having characteristic response wavelengths λ_1, λ_2, and λ_5, those at location 130 wavelengths λ_1, λ_3 and λ_4 and finally those at location 130 having wavelengths λ_2, λ_4, and λ_5. Also at each grating location the fibre has a respective reflective tap 122, 132 and 142.

The optical sources 110 through 114 have data inputs 125, 135 and 145, for the supply of data intended to be received at the grating locations 120, 130 and 140 by way of the reflective taps 122, 132 and 142. The data input 125, which carries data intended for reception by a user assigned to the tap 122, is coupled to drive the optical sources 110, 111 and 114, having wavelengths corresponding to the three wavelength responses of the gratings at the location 120. Similarly the data input 135 is coupled to the optical sources 110, 112 and 113 and the data input 145 to the sources 111, 113 and 114.

As with the embodiment described with respect to Fig. 1 (b) in conjunction with Figs. 2 to 4, a spectrum analyzer and correlator is coupled to each tap 122, 132, 142 and an auto correlation function is performed in wavelength space between the signals received at each of the taps and the digital codes assigned to the taps, in the manner described above. In this way data intended to be transmitted to each of the users associated with each reflective tap along the optical fibre 100, may be discriminated.

The invention has been described by way of example and modifications may be made without departing from the scope of the invention. In particular, the invention is not restricted to the use of optical fibre waveguides and any other suitable optical waveguide may be used, such as those formed using lithium niobate, III-V semiconductor and silica technologies. More than three gratings may also be employed at each location. The invention is also not restricted to the use of Prime Codes and any other suitable code structure may be employed. All that is required is that the digital code sequence chosen is suitable to support the number of gratings per location and the number of locations.

CLAIMS

1. An optical waveguide Bragg grating system comprising a length of optical waveguide having a plurality of Bragg grating locations spaced apart along its length, each grating location containing a plurality of superimposed Bragg gratings formed thereat, each of the superimposed gratings at a respective location having a characteristic response wavelength different from the other gratings at that location, each location being assigned a unique digital code representative of a unique set of response wavelengths of the gratings at that location, an optical source for providing an optical signal to the optical waveguide, the signal having a bandwidth which includes the response wavelength of each grating at each location, a correlator for correlating in wavelength space combined optical responses from all locations with each code, whereby the responses from each grating location may be uniquely determined.

2. The grating system of Claim 1 in which a signal amplitude threshold circuit is coupled to an output of the correlator to increase discrimination of the responses from the respective grating locations.

3. The grating system of Claim 1 or 2 in which the digital codes assigned to the grating locations are Prime Codes.

4. The grating system of any preceding claim in which the Bragg grating locations are mechanical strain-sensing locations, a change in the wavelength response from a respective location being indicative of a change in mechanical strain induced in the optical waveguide

at that location.

5. An optical CDMA data communications system comprising a length of optical waveguide having a plurality of Bragg grating locations spaced apart along its length, each grating location containing a plurality of superimposed Bragg gratings formed thereat, each of the superimposed gratings at a respective location having a characteristic response wavelength different from the other gratings at that location, each location being assigned a unique digital code representative of a unique set of response wavelengths of the gratings at that location and having a respective reflective tap, a plurality of optical sources coupled to the optical waveguide, each source having a unique respective wavelength corresponding to the characteristic response wavelength of a different respective one of the gratings at the plurality of Bragg grating locations, a data input for feeding data intended to be received at the reflective tap of a grating location to each optical source having a wavelength corresponding to the characteristic response wavelength of each grating at said grating location and a correlator coupled to each reflective tap for correlating in wavelength space optical signals received at a respective tap with each digital code, whereby data signals intended for that tap may be discriminated.

6. The system of Claim 5 in which a signal amplitude threshold circuit is coupled to an output of each correlator to increase discrimination of the responses from the respective grating locations.

7. The system of Claim 5 or 6 in which the digital codes assigned to the grating locations are Prime Codes.

8. The system of any preceding claim in which the optical waveguide is a length of optical fibre.

9. The system of Claim 8 in which the optical fibre is single mode optical fibre.

10. An optical waveguide Bragg grating system substantially as herein described with reference to and as shown in Figs 1 (b) and 2 to 4 of the drawings.

11. An optical CDMA data communications system substantially as herein described with reference to and as shown in Fig. 5 of the drawings.

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INVESTOR IN PEOPLE

Application No: GB 0103482.6
Claims searched: 1 to 11

Examiner: Jane Croucher
Date of search: 28 November 2001

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): G1A (ACA, ABF), H4B (BKX)

Int Cl (Ed.7): G02B (6/34), H04J (14/02)

Other: Online: WPI, EPODOC, PAJ, INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
	None	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

STIC Scientific and Technical Information Center

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SEARCH REPORT

STIC Database Tracking Number: 520335

To: STEPHEN RALIS
Location: RND-8D31
Art Unit: N/A
Monday, August 01, 2016

Case Serial Number: 14686161

From: DIANE JACKSON
Location: EIC2800
JEF-4B68
Phone: (571)272-3260

diane.jackson@uspto.gov

Search Notes

Hi,

RE: Serial Number 14686161 and US Patent 7030971

Attached are litigation search results in Lexis Nexis, Courtlink and ProQuest.

No Litigation was found.

If you have any questions, please feel free to contact me.

Thanks,

Diane

Application Number Information

Application Number: **14/686161** Assignments	AIA (First Inventor to File): **NO**	TYPE ENT: **U**
Filing or 371(c) Date: **06/16/2015** eDan	Examiner Number: **81637 / RALIS, STEPHEN**	IFW Madras
Effective Date: **04/14/2015**	Group Art Unit: 3992	
Application Received: **04/14/2015**	Class/Subclass: **356/035.500**	
Patent Number:	Interference Number:	
Issue Date: **00/00/0000**	Unmatched Petition: **NO**	
Date of Abandonment: **00/00/0000**	L&R Code: Secrecy Code:**1**	
Attorney Docket Number: **300099**	Third Level Review: **NO**	Secrecy Order: **NO**
Status: **30 /DOCKETED NEW CASE - READY FOR EXAMINATION**		Status Date: **06/25/2015**
Confirmation Number: **5544**	Oral Hearing: **NO**	Lost Case: **NO**

Title of Invention: **NATURAL SPAN REFLECTOMETRY WITH SENSING ZONE SEGMENTS**

Continuity/Reexam Information for 14/686161

Parent Data

14686161, filed 06/16/2015 is a continuation of 14190478, filed 02/26/2014
14190478 is a reissue of 11056630, filed 02/07/2005 ,now U.S. Patent #7030971
11056630 Claims Priority from Provisional Application 60599437, filed 08/06/2004

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Patno=7030971

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056630 (11) 7030971 April 18, 2006

UNITED STATES PATENT AND TRADEMARK OFFICE GRANTED PATENT

7030971

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Link to Claims Section

April 18, 2006

Natural fiber span reflectometer providing a virtual signal sensing array capability

REISSUE:
February 26, 2014 - Reissue Application filed, Ex. Gp.: 2877; Re. S.N. 14/190,478 , (O.G. May 13, 2014)
May 14, 2015 - Reissue Application filed, Ex. Gp.: 2877; Re. S.N. 14/686,170 , (O.G. September 1, 2015)
June 15, 2015 - Reissue Application filed, Ex. Gp.: 2877; Re. S.N. 14/686,188 , (O.G. July 14, 2015)
June 16, 2015 - Reissue Application filed, ; Re. S.N. 14/686,194 , (O.G. July 14, 2015)
June 16, 2015 - Reissue Application filed, Ex. Gp.: 2877; Re. S.N.: 14/686,205 , (O.G. July 28, 2015)
June 17, 2015 - Reissue Application filed, Ex. Gp.: 2877; Re. S.N. 14/741,822 , (O.G. July 14, 2015)
June 17, 2015 - Reissue Application filed, Ex. Gp.: 2877; Re. S.N.: 14/741,768 , (O.G. August 18, 2015)
June 17, 2015 - Reissue Application filed, Ex. Gp.: 2877; Re. S.N.: 14/741,857 , (O.G. August 4, 2015)

INVENTOR: Payton, Robert Michael - Portsmouth, Rhode Island, United States of America (US), United States of America ()

APPL-NO: 056630 (11)

FILED-DATE: February 7, 2005

GRANTED-DATE: April 18, 2006

PRIORITY: February 7, 2005 - 11056630, United States of America (US)

ASSIGNEE-PRE-ISSUE:
April 7, 2005 - ASSIGNMENT OF ASSIGNORS INTEREST (SEE DOCUMENT FOR DETAILS)., NAVY, UNITED STATES OF AMERICA, THE, AS REPRESENTED BY THE DEPARTMENT OF, 1176 HOWELL STREET, (ATTN: CODE 00OC), NAVAL UNDERSEA WARFARE CENTER, OFFICE OF COUNSEL, NEWPORT, RHODE ISLAND, UNITED STATES OF AMERICA (US), 02841-1708, Reel and Frame Number: 016024/0426

ASSIGNEE-AT-ISSUE:
The United States of America represented by the Secretary of the Navy, Washington, District of Columbia, United States of America (US), U.S. Federal government (06)

LEGAL-REP: Kasischke, James M. ; Nasser, Jean-Paul A. ; Stanley, Michael P.

PUB-TYPE: April 18, 2006 - Patent without a pre-grant publication (B1)

PUB-COUNTRY: United States of America (US)

LEGAL-STATUS:

April 7, 2005 - ASSIGNMENT
July 7, 2009 - FEE PAYMENT
September 9, 2013 - FEE PAYMENT
May 13, 2014 - REISSUE APPLICATION FILED
July 14, 2015 - REISSUE APPLICATION FILED

July 14, 2015 - REISSUE APPLICATION FILED
July 14, 2015 - REISSUE APPLICATION FILED
July 28, 2015 - REISSUE APPLICATION FILED
August 4, 2015 - REISSUE APPLICATION FILED
August 18, 2015 - REISSUE APPLICATION FILED
July 7, 2009 - Payment of Maintenance Fee, 4th Year, Large Entity.
September 9, 2013 - Payment of Maintenance Fee, 8th Year, Large Entity.

FILING-LANG: English (EN) (ENG)

PUB-LANG: English (EN) (ENG)

REL-DATA:

Provisional Application Ser. No. 60599437, August 6, 2004, PENDING

US-MAIN-CL: 356#35.5

US-ADDL-CL: 356#478, 356#484

CL: 356

SEARCH-FLD: 356#35.5, 356#73.1, 356#477, 356#478, 356#484, 367#140, 367#141

IPC-MAIN-CL: [8] G01L 001#24 (20060101) Advanced Inventive 20060418 (A F I B H US)

IPC-ADDL-CL: [8] G01B 009#02 (20060101) Advanced Inventive 20060418 (A L I B H US)

PRIM-EXMR: Toatley, Jr., Gregory J.

ASST-EXMR: Lyons, Michael A.

REF-CITED:

5194847, March 16, 1993, Taylor et al., United States of America (US)
5686986, November 11, 1997, Li et al., United States of America (US)
6043921, March 28, 2000, Payton, United States of America (US)
6173091, January 9, 2001, Reich, United States of America (US)
6285806, September 4, 2001, Kersey et al., United States of America (US)

NON-PATENT LITERATURE:
R. Hughes and J. Jarzynski, "Static Pressure Sensitivity Amplification in Interferometric Fiber-Optic Hydrophones", Applied Optics, Jan. 1, 1980, vol. 19., No. 1, USA.0018914716

CORE TERMS: optical, phase, phi, fiber, path, omega, electrical, cos, span, sensor, lightwave, correlation, wave, sin, psi, composite, frequency, receiver, correlator, virtual, laser, electronic, oscillator, r.f, tau, sequence, interrogation, demodulator, acoustic, array

ENGLISH-ABST:

A CW lightwave modulated by a continuously reiterated binary pseudorandom code sequence is launched into an end of a span of ordinary optical fiber cable. Portions of the launched lightwave back propagate to the launch end from a continuum of locations along the span because of innate fiber properties including Rayleigh scattering. This is picked off the launch end and heterodyned to produce a r.f. beat signal. The r.f. beat signal is processed by a plurality (which can be thousands) of correlator type binary pseudonoise code sequence demodulators respectively operated in different delay time relationships to the timing base of the reiterated modulation sequences. The outputs of the demodulators provide r.f. time-domain reflectometry outputs representative of signals (e.g., acoustic pressure waves) incident to virtual sensors along the fiber at positions corresponding to the various time delay relationships.

NO-OF-CLAIMS: 22

EXMPL-CLAIM: 1

NO-OF-FIGURES: 13

NO-DRWNG-PP: 13

GOVT-INTEREST:

STATEMENT OF GOVERNMENT INTEREST

[0002]The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefore.

PARENT-PAT-INFO:

[0001]Applicant claims the benefit of a provisional application, No. 60/599,437 which was filed on 6 Aug. 2004, and which is entitled "Continuous Rayleigh Effect Sensor Backscattering Heterodyne Optical Sensor System" by Robert M. Payton.

SUMMARY:

CROSS-REFERENCE TO RELATED APPLICATIONS

[0003]"Natural Fiber Span Reflectometer Providing a Spread Spectrum Virtual Sensing Array Capability" (Navy Case No 96650) filed on even date herewith in the name of Robert M. Payton, hereby incorporated herein by reference in its entirety.

[0004]"Natural Fiber Span Reflectometer Providing A Virtual Phase Signal Sensing Array Capability" (Navy Case No. 96518) filed on even date herewith in the name of Robert M. Payton, hereby incorporated herein by reference in its entirety.

[0005]"Natural Fiber Span Reflectometer Providing a Virtual Differential Signal Sensing Array Capability" (Navy Case No. 96519) filed on even date herewith in the name of Robert M. Payton, hereby incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[0006](1) Field of the Invention

[0007]The present invention relates generally to the field of time-domain reflectometers. More specifically, it relates to such reflectometers which are a part of a photonic system application in which the object of the reflectometry is a span of fiber which has an interrogation signal launch end and a remote end. The invention enables the provision of a linear array of virtual sensors along the span. One particular type of application toward which the invention is directed are acoustic security alarm systems in which the span serves as a perimeter intrusion monitoring line.

[0008](2) Description of the Prior Art

[0009]The U.S. Department of the Navy has been engaged in the development of towed acoustic arrays which are reflectometric systems in which the object of the reflectometry is a fiber span having an interrogation signal launch end and a remote end. One such development involves forming a towed array of acoustic sensors along the span by the costly process of irradiating Bragg reflective gratings into the fiber cable. These reflective gratings form the array of sensors of the reflectometry scheme of these systems. These towed arrays have a length of the order of at least 1.0 km, and the need to irradiate the fiber has resulted in the fiber spans costing hundreds of thousands of dollars each.

[0010]The Department of the Navy development activities have been further tasked to apply their creative efforts to homeland defense problems. As part of this effort there is under consideration the use of a reflectometer in which a fiber span is the object of the reflectometry. In this scheme, the fiber span provided with acoustic sensors would be used as an intrusion detector to monitor the perimeter of an area desired to be secure. The span lengths for this type of application include lengths of the order of 5 km, (links of a U.S. border protection network, oil line protection, chemical plant protection, etc.). In such perimeter monitoring applications thousands of acoustic sensors would be required along the fiber span.

[0011]The cost of manufacturing such perimeter monitoring spans employing reflective Bragg grating sensors has been an obstacle to their use in perimeter intrusion monitoring applications. Thus, there is considerable interest in the development of a reflectometer system in which a fiber span is the object of the reflectometry optic array that does not require the high cost of Bragg reflective acoustic sensors.

[0012]Previous effort in solving related problems are described by the following patents:

[0013]U.S. Pat. No. 5,194,847 issued Mar. 16, 1993 to H. Taylor and C. Lee discloses an apparatus for sensing intrusion into a predefined perimeter which comprises means for producing a coherent pulsed light, which is injected into an optical sensing fiber having a first predetermined length and positioned along the predefined perimeter. A backscattered light in response to receiving the coherent light pulses is produced and coupled into an optical receiving fiber. The backscattered light is detected by a photodetector and a signal indicative of the backscattered light is produced. An intrusion is detectable from the produced signal as indicated by a change in the backscattered light. To increase the sensitivity of the apparatus, a reference fiber and interferometer may also be employed.

[0014]U.S. Pat. No. 6,285,806 issued on Sep. 4, 2001 to A. Kersey et al., discloses an apparatus and method for measuring strain in an optical fiber using the spectral shift of Rayleigh scattered light. The interference pattern produced by an air gap reflector and backscatter radiation is measured. Using Fourier Transforms, the spectrum of any section of fiber can be extracted. Cross correlation with an unstrained measurement produces a correlation peak. The location of the correlation peak indicates the strain level in the selected portion of optical fiber.

[0015]The above patents do not show how to obtain signals representing acoustic pressure signals incident upon a fiber span (to detect perimeter intrusion) at a very large number of sensing stations without involving high manufacturing costs. Consequently, those skilled in the arts will appreciate the present invention which addresses these and other problems.

SUMMARY OF THE INVENTION

[0016]The objects of the present invention include the provision of:

- -

  (1) A time-domain reflectometer wherein an optical fiber span is the object of the reflectometry, and which provides output signals representative of acoustic pressure waves incident the span solely by virtue of the natural, or innate, properties of commercial grade optical fiber cables.
- -

  (2) The reflectometer described in object number (1), above, capable of providing acoustic wave signal sensing lengths of 5.0 km or more.
- -

  (3) The reflectometer described in object number (2), above, which facilitates the provision of a very large plurality (e.g. 5,000 or more) virtual acoustic sensors along the span.
- -

  (4) The reflectometer described in object number (1), above having a mode of operation which inherently attenuates undesired noises due to span line discontinuities, such as reflections caused by fiber cable

couplings.

- ~

(5) The reflectometer described in objects numbered (1) through

- ~

(4), above, having special utility as a perimeter intrusion monitoring line for an acoustic security alarm system.

- ~

(6) The reflectometer described in object numbered (1), above, which is capable of providing output signals in the form of a phase signal which varies linearly with the acoustic pressure wave.

- ~

(7) The reflectometer described in object numbered (3), above, which is capable of providing output signals in the form of phase differential signals across pairs of the virtual sensors.

- ~

(8) The reflectometer described in the object number (7), above, providing a capability of programmably selecting a pair, or pairs, of virtual acoustic sensors across which the phase signals are picked off, from among the plurality of virtual signals along the span.

[0026]These and other objects, features, and advantages of the present invention will become apparent from the drawings, the descriptions given herein, and the appended claims. However, it will be understood that the above listed objects and advantages of the invention are intended only as an aid in understanding aspects of the invention, and not intended to limit the invention in any way, and do not form a comprehensive list of objects, features, and advantages.

[0027]Accordingly, a time-domain reflectometer is provided for sensing and providing output signals representative of acoustic wave signals incident on the fiber span which is the object of the reflectometry, wherein the innate properties of low cost, commercially available fiber optic cables are employed to create a plurality (upwardly extending to very large numbers, e.g., 5000 and more) virtual sensors.

[0028]The present invention is implemented as follows: Time and spatial domain multiplexing and de-multiplexing of optical signals is accomplished by an electronic-delay or time of-transversal-delay coupled with modulated-retransmission of a master or reference carrier wave. Each individual optical signal occupies a unique time-delay slot or bin. A master or carrier wave is modulated with each individual optical signal and delayed by the appropriate time interval specific to a particular signal. All such signals are combined and simultaneously transmitted as a composite optical signal to a receiver where these are collected and photodetected. By correlating the photodetected composite optical signal with the master or reference carrier wave, each individual optical signal is sorted or demultiplexed into separate electronic signal channels. The continuous wave nature of the master or reference carrier wave provides more power than a pulsed optical wave and heterodyne optical reception of the invention allows a very low optical detection threshold or noise floor. The invention provides significant improvement over other systems because the optical noise floor is lowered considerably over more conventional means.

[0029]The invention applies to several applications. The invention allows audio bandwidth (tens of kilohertz bandwidth) providing time-domain reflectometry measurements of fiber optical cables or other optical mediums such as glass, air, water, etc. Other time-domain reflectometry methods do not sample the optical medium fast enough to detect tens of kilohertz bandwidth variations in the medium. The invention also relates to fiber optic sensors and optical sensors generally. A fiber optic sensor array is typically time-domain multiplexed by the time-of-transversal of an interrogation lightwave to each sensor and back to a common optical collection and detection point. The invention relates generally to both amplitude and phase type optical senor arrays. The invention is an enabling technology for a Department of Navy development known as the Rayleigh Optical Scattering and Encoding (ROSE) sensor system. The spatial separation of segmentation of a ROSE acoustic array into spatial channels is enabled by the invention.

[0030]The invention relates to acoustic security alarm systems, Naval towed arrays for sensing underwater acoustic signals, fiber optic bugging devices, and many other potential ROSE applications. The invention also relates to non-fiber optical sensors such as: laser velocimeters; lasers imagers; laser radar; laser rangers; and remote laser acoustic, strain, motion or temperature measurement devices.

DRWDESC:

BRIEF DESCRIPTION OF THE DRAWINGS

[0031]A more complete understanding of the invention and many of the attendant advantages thereto will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawing, wherein like reference numerals refer to like parts and wherein:

[0032]FIG. 1 is a graphical depiction of certain underlying physical mechanisms of polarization;

[0033]FIG. 2 is a block diagram helpful in understanding the concept of launch of an interrogation signal along an optical fiber span providing a virtual array of pressure wave sensors by retrieval of backscatter from Rayleigh Optical Scatter (ROS) effects;

[0034]FIG. 3 is a block diagram of a natural fiber span time-domain reflectometer system in accordance with the present invention;

[0035]FIG. 4 is an electrical schematic of a balanced heterodyne optic detector circuit;

[0036]FIG. 5 is an electrical schematic of an alternative embodiment of a photodetector type heterodyner;

[0037]FIG. 6 is a block diagram of a programmable correlator subsystem, which enables spatial sampling of optical signals on the fiber optic span of the system of FIG. 3, in order to provide a virtual array of acoustic wave sensors therealong;

[0038]FIG. 7 is a block diagram depiction of a set of phase demodulator circuit assemblies which receives the outputs of the programmable correlator subsystem of FIG. 6;

[0039]FIG. 8 is a block diagram of one of the phase demodulator circuit assemblies of the set of FIG. 7;

[0040]FIG. 9 is a block diagram disclosing details of an I & Q demodulator component in a phase demodulator circuit assembly of FIG. 8;

[0041]FIG. 10 is a block diagram disclosing details of a digital embodiment of the phase detector component phase demodulator circuit assembly of FIG. 8;

[0042]FIG. 11 is a block diagram disclosing details of an analog embodiment of the phase detector component phase demodulator circuit assembly of FIG. 8;

[0043]FIG. 12 is a block diagram of a programmable routing and phase signal switching network which provides selective pairing of the outputs of the set of phase demodulators of FIG. 7 to provide differential phase signals across pairs of virtual sensors along the fiber span in accordance with the present invention; and

[0044]FIG. 13 is a diagrammatic depiction of embodiment of invention of FIG. 3 in which portions of the optical fiber span are wound around a hollow mandrel.

DETDESC:

DESCRIPTION OF THE PREFERRED EMBODIMENT

(1) Description of Underlying Theories

[0045]a. Heterodyne Optical Detection

[0046]Optical receivers are built around photodetectors which detect optical power rather than instantaneous electric field. Typically the photodetector output current is proportional to the incident optical power. This relationship severely limits the dynamic range of an incoherent optical receiver because for every decibel of optical power lost in a receiver system two decibels of receiver output current is lost. The square law characteristics of photodetectors limits typical incoherent optical receivers (often called video detection receivers) to dynamic ranges of less than 80 dB and optical detection noise floors to greater than −80 dBm per Hertz bandwidth. As illustration, suppose an electric field $E_{(s)}(t)$ [volt/meter] immersed in a material of impedance η [Ohms] impinges upon a photodetector of responsivity [ampere/watt] loaded by resistor $R_{(1\ )}$and amplified by amplification A, then the optical power $P_{(s\ )}$by amplification A, is:

[0047]Ps⁡(t)=⟨E⇀s⁡(t)·E⇀s⁡(t)⟩η(1) The photodetector output current [amperes] is: $i(t)=P_{(S)}(t)$ (2) The photoreceiver output [volts] is thus: $v(t)=AR_{(L)}i(t)=AR_{(L)}P_{(S)}(t)$ (3)

[0048]The output fades only if the optical signal power goes to zero because the vector dot product of an optical signal against itself has no polarization or phase effects. This lack of fading due to polarization or phase comes at a cost: phase information is lost and signal to noise ratios are severely impacted.

[0049]A coherent optical receiver takes advantage of the square law characteristics of photodetectors. A coherent optical receiver combines two optical beams, a signal and a local oscillator, together to form an interference. The interference between these optical waves produces a "beat" which allows the measurement of the phase difference between the signal and the local oscillator. This interference produces an amplitude, polarization, and phase sensitive receiver output. In order to consider these effects a discussion of the polarization state of plane waves is in order. A plane wave contains two orthogonal vector components which are also orthogonal to the direction of propagation of the wave. For purposes of discussion we will consider the plane wave to be oriented so that the vector components of the electromagnetic field lie in an X-Y plane and that the wave propagates in the Z direction. However, this choice of axes is completely arbitrary. In practice, the wave can be oriented in any propagation direction. In order to simplify discussions, a simple change of coordinates will make this discussion completely general.

[0050]The polarization of an electromagnetic (or optical) plane wave, p, is described by a minimum of five parameters. There are two basic ways of specifying these parameters. The first way leads to a description which is oriented towards that which is directly obtained from physical measurements.

[0051]E⇀p⁡(Epx,Epy,Φpx,Φpy,ωp,t)=[Epx⁡(t)⁢cos⁡(ωp⁢t+Φpx)Epy⁡(t)⁢cos⁡(ωp⁢t+Φpy)](4) The second manner of describing the polarization state of a wave, p, is oriented more towards the underlying physical mechanisms of polarization. See FIG. 1. The description is made in terms of spatial and temporal parameters:

[0052]E→p⁡(Ep,?p,ψp,φp,ωp,t)=Ep⁡(t)⁡[cos⁡(?p)sin⁡(?p)-sin⁡(?p)cos⁡(?p)]⁢[cos⁡(ψp)00sin⁡(ψp)]⁢[cos⁡(ωp⁢t+φp)sin⁡(ωp⁢t+φp)](5) Alternatively, dropping the full variable list in the parentheses and expanding:

[0053]E→p⁡(t)=Ep⁡(t)⁡[cos⁡(?p)sin⁡(?p)-sin⁡(?p)cos⁡(?p)]⁢[cos⁡(ψp)00sin⁡(ψp)]⁢[cos⁡(φp)-sin⁡(φp)sin⁡(φp)cos⁡(φp)]⁢[cos⁡(ωp⁢t)sin⁡(ωp⁢t)](6)

[0054]If $E_{(p\ )}$is constant, the electrical power of this wave can be shown to be constant and equal to:

[0055]Pp⁡(t)=⟨E→p⁡(t)·E→p⁡(t)⟩η=Ep22⁢η(7) When two waves, S (signal) and L (local oscillator), interfere at the input of a photoreceiver, the output is:

[0056]vout⁡(t)=ARL⁢i⁡(t)=ARL⁢⁢⟨E→s⁡(t)·E→s⁡(t)+E→L⁡(t)·E→L⁡(t)+2⁢E→L⁡(t)·E→s⁡(t)⟩η⁢⁢vout⁡(t)=vL⁡(t)+vs⁡(t)+vLS⁡(t)=ARL⁢⁢(PL⁡(t)+Ps⁡(t)+PLS⁡(t))(8) If the optical power of the local oscillator and signal lightwaves remain constant, a constant photocurrent develops for the self-interference terms ($P_{(S\ )}$and $P_{(L)}$). However, if either the local oscillator or the signal lightwaves have any temporal variation in polarization or phase, the cross interference term ($P_{(LS)}$) will be time dependent even if the power of each lightwave remains constant. Solving for the cross interference term, we obtain:

[0057]vLS⁡(t)=ARL⁢η⁢EL⁡(t)⁢Es⁡(t)⁡[cos⁡(Δ?)⁢cos⁡(Δψ)⁢cos⁡(Δω⁢⁢t+Δφ)+sin⁡(Δ?)⁢sin⁡(2⁢ψ_)⁢sin⁡(Δω⁢⁢t+Δφ)]⁢⁢vLS⁡(t)=2⁢ARL⁢⁢PL⁡(t)⁢Ps⁡(t)⁡[cos⁡(Δ?)⁢cos⁡(Δψ)⁢cos⁡(Δω⁢⁢t+Δφ)+sin⁡(Δ?)⁢sin⁡(2⁢ψ_)⁢sin⁡(Δω⁢⁢t+Δ?)](9) Where the following definitions are made: Δ?=?$_{(S)}$−?$_{(L)}$Δψ=ψ$_{(S)}$−ψ$_{(L)}$2[overscore (ψ)]=ψ$_{(S)}$+ψ$_{(L)}$Δω=ω$_{(S)}$−ω$_{(L)}$Δϕ=ϕ$_{(S)}$−ϕ$_{(L)}$ (10)

[0058]The optical cross-interference portion of the receiver output will fade due to polarization even if the local oscillator and the signal lightwaves both do not have zero optical powers. This condition will occur if: *O*=cos(Δs)cos(Δψ)cos(Δω*t*+Δϕ)=sin(Δs)sin(2[overscore (ψ)])sin(Δω*t*+ΔΦ) (11) Also, equivalently when the condition will occur:

[0059][00]=[cos⁡(Δ?)⁢cos⁡(Δψ)⁢cos⁡(Δω⁢⁢t+Δφ)sin⁡(Δ?)⁢sin⁡(2⁢ψ_)⁢sin⁡(Δω⁢⁢t+Δφ)](12)

[0060]When heterodyne optical detection is employed (Δω is non-zero, the local oscillator has a different frequency from the signal), the conditions for a fade are shown in Table 1. When homodyne detection is employed (Δω is zero), both phase and polarization fading occur. The conditions for a homodyne fade are shown in Table 2. Heterodyne detection is therefore seen to be superior to homodyne because the probability of a fade is fully one half as likely.

[0061]

Search terms may have been found within the contents of this table. Please see the table in the original document.

[0062]

Search terms may have been found within the contents of this table. Please see the table in the original document.

[0063]Given the conditions for and the functional relation of a fade, the question now arises as to how a fade can be prevented. Since the signal is being measured, no a priori knowledge is assumed and therefore $E_{(S)}$, $s_{(S)}$, Ψ$_{(S)}$, Φ$_{(S)}$ are all probably unknown quantities. If fading is prevented, then no loss of information occurs and determination of these four parameters is possible. In order to decode the optical receiver output into these parameters, at least four independent measurements must be made to uniquely determine these four independent variables. However, if the interfering optical beam (or beams) of the local oscillator are unknown, then additional independent measurements must be made (four additional measurements for each unknown beam) to determine the $E_{(L)}$, $s_{(L)}$, Ψ$_{(L)}$, or Φ$_{(L)}$ for each optical beam of the local oscillator. The cross-reference output of the photoreceiver, $v_{(LS)}(t)$, offers the only means by which to measure these parameters. If the parameters cannot be determined from this output, then an optical fade cannot be ruled out.

[0064]We shall now examine the information which can be gleaned from this output. Define the following functions.

[0065]vI⁡(EL,ES,Δ?,Δψ)=ARL⁢2⁢η⁢EL⁡(t)⁢ES⁡(t)⁢cos⁡(Δ?)⁢cos⁡(Δψ)=ARL⁢⁢PL⁡(t)⁢PS⁡(t)⁢cos⁡(Δ?)⁢cos⁡(Δψ)⁢⁢vQ⁡(EL,ES,Δ?,2⁢ψ_)=ARL⁢2⁢η⁢EL⁡(t)⁢ES⁡(t)⁢sin⁡(Δ?)⁢sin⁡(2⁢ψ_)=ARL⁢⁢PL⁡(t)⁢PS⁡(t)⁢sin⁡(Δ?)⁢sin⁡(2⁢ψ_)(13)

[0066]In the homodyne case (Δω is zero), we obtain the following output:

[0067]vLS⁡(t)=2⁢ARL⁢⁢PL⁡(t)⁢PS⁡(t)⁢(cos⁡(Δ?)⁢cos⁡(Δψ)⁢cos⁡(Δφ)+sin⁡(Δ?)⁢sin⁡(2⁢ψ_)⁢sin⁡(Δφ))⁢⁢vLS⁡(t)=2⁢vI⁡(EL,ES,Δ?,Δψ)⁢cos⁡(Δφ)+2⁢vQ⁡(EL,ES,Δ?,2⁢ψ_)⁢sin⁡(Δφ)(14) The homodyne output only allows the measurement of one quantity. The output provides only one independent measurement (one equation) whereas a minimum of four are required. In the heterodyne case (Δω is non-zero), the output is:

[0068]vLS⁡(t)=2⁢ARL⁢⁢PL⁡(t)⁢PS⁡(t)⁢(cos⁡(Δ?)⁢cos⁡(Δψ)⁢cos⁡(Δω⁢⁢t+Δφ)+sin⁡(Δ?)⁢sin⁡(2⁢ψ_)⁢sin⁡(Δω⁢⁢t+Δφ))⁢⁢vLS⁡(t)=ARL⁢η⁢EL⁡(t)⁢ES⁡(t)⁢(cos⁡(Δ?)⁢cos⁡(Δψ)⁢cos⁡(Δω⁢⁢t+Δφ)+sin⁡(Δ?)⁢sin⁡(2⁢ψ_)⁢sin⁡(Δω⁢⁢t+Δφ))⁢⁢vLS⁡(t)=2⁢vI⁡(EL,ES,Δ?,Δψ)⁢cos⁡(Δω⁢⁢t+Δφ)+2⁢vQ⁡(EL,ES,Δ?,2⁢ψ_)⁢sin⁡(Δωt+Δφ)(15)

[0069]Since sine and cosine waves are orthogonal, the heterodyne receiver provides two independent measurements by mixing down to baseband the Δω radian frequency components. Thus, two outputs are obtained:

[0070]VI⁡(t)=⟨vLS⁡(t)⁢cos⁡(Δω⁢⁢t)⟩=vI⁡(EL⁡(t),ES⁡(t),Δ?⁡(t),Δψ⁡(t))⁢cos⁡(Δφ⁡(t))⁢⁢VQ⁡(t)=⟨vLS⁡(t)⁢sin⁡(Δω⁢⁢t)⟩=vQ⁡(EL⁡(t),ES⁡(t),Δ?⁡(t),2⁢ψ_⁡(t))⁢sin⁡(Δφ⁡(t))(16)

[0071]b. Correlation or Time-Delay Multiplexing

[0072]In many optical sensor applications, the lightwave signal heterodyne-detected by the photodetector system is a composite optical signal formed from the superposition of many individual optical signals. When the receiver lightwave is generated by backscatter, the composite optical signal is the superposition of individual light signals generated by a continuum of reflections of an interrogation light source. The temporal and spatial characteristics of each reflector or reflective region creates a modulation of the interrogation light source. The time-delay, amplitude, polarization and phase states control the backscattered-modulation of these individual optical signals arriving at the photodetector with a unique time-delay interval can be separated into channels which sort the optical signals into time-delay slots or bins. Depending upon how the signals are generated, these channels can represent spatial regions in space or time-delay slots of a time-domain reflectometer mechanism.

[0073]Let an interrogation lightwave source be generated by modulating the amplitude, phase or polarization of a coherent lightwave with a time-structured correlation code, c(t). The correlation code, c(t) can be a series of pulses, chirps, binary sequences or any other type of code which provides the required correlation characteristics. If the lightwave source is: $E_{(SS)}(t)=E_{(SS\ )}$cos(ω$_{(S)}t$) (17) Then an amplitude modulated interrogation source is: $E_{(i)}(t)=\mu_{(A)}c(t)E_{(SS\ )}$cos(ω$_{(S)}t$) (18) Alternatively, a phase modulated interrogation source is: $E_{(i)}(t)=E_{(SS\ )}$cos(ω$_{(S)}t+\mu_{(p)}c(t)$). (19) If c(t) is chosen to be temporally structured properly, then:

[0074]Ri⁡(τ)=⟨Ei⁡(t)⁢Ei⁡(t+τ)⟩≈[ESS22;τ≈00;otherwise(20) c(t) must be chosen so that an a priori decoding/demultiplexing function, d(t), exists such that:

[0075]b⁡(t,τ)=⟨d⁡(t)⁢Ei⁡(t+τ)⟩≈[ξ⁢⁢ESS⁢cos⁡(Δω⁢⁢t+φ);τ≈00;otherwise(21)

[0076]For instance, suppose the interrogation wave is: $E_{(i)}(t)=\mu_{(A)}c(t)E_{(ss\ )}$cos(ω$_{(S)}t$) (22) and:

[0077]Rc⁡(τ)=⟨c⁡(t)⁢c⁡(t-τ)⟩≈[1;τ≈00;τ≠0(23) then a valid decoding and temporal and spatial domains demultiplexing function is:

[0078]d⁡(t)=µd⁢C⁡(t)⁢EL⁢cos⁡((Δω+ωS)⁢t+φ)⁢⁢b⁡(t,τ)=⟨d⁡(t-τ)⁢Ei⁡(t)⟩=[µd⁢µA⁢ESS⁢EL2⁢cos⁡(Δω⁡(t-τ)+φ-ωS⁢τ);τ≈00;otherwise(24)

[0079]Therefore, delaying the correlation decoding/demultiplexing function d(t) allows demultiplexing of delay multiplexed signals identifiable by speed of propagation and distance of flyback travel. Suppose an optical wave is formed a summation of delayed signals modulated onto the interrogation wave $E_{(i)}(t)$, then the received wave, $E_{(b)}(t)$, is:

[0080]Eb⁡(t)=∑n=1N⁢⁢An⁡(t-τn)⁢µA⁢c⁡(t-τn)⁢ESS⁢cos⁡(ωS⁡(t-τn)+Φn⁡(t-τn))(25)

[0081]Then multiplying by the decoding/demultiplexing function, d(t−τ$_{(m)}$), we obtain:

[0082]d⁡(t)=µd⁢c⁡(t)⁢EL⁢cos⁡((Δω+ωS)⁢t+φ)⁢⁢b⁡(t,τm)=⟨d⁡(t-τm)⁢Eb⁡(t)⟩⁢⁢b⁡(t,τm)≈µd⁢µA⁢ESS⁢EL2⁢Am⁡(t-τm)⁢cos⁡(Δω⁡(t-τm)+φ-ωS⁢τm+Φm⁡(t-τm)).(26) Because τ$_{(n\ )}$is unique, the amplitude signal $A_{(m)}$(t−τ$_{(m)}$) and the phase signal Φ$_{(m)}$(t−τ$_{(m)}$) are both extracted from $E_{(b)}(t)$ by multiplying by the decoding/demultiplexing function, d(t−$_{(m)}$). The technique is applicable to a wide variety of other optical signal multiplexing applications. Specifically, the technique can be used to spatially separate optical signals arriving from a temporally varying time-domain reflectometer optical backscatter process from an array of fiber optic acoustic sensors. (2) Description and Operation of the Rayleigh Optical Scattering and Encoding (ROSE) System

[0083]a. ROSE Optical Phase Sensor Interrogation Enables Sensor Subsystem

[0084]In order to more fully describe the capabilities and new features of the invention, the application of the invention to a subsystem **1**, FIG. 2, of ROSE which launches an interrogation signal onto fiber span **9** and retrieves lightwave back propagation from a continuum of locations along the span. Back propagation mechanisms may include Rayleigh Optical Scattering (ROS) and other effects generated within the optical fiber. Rayleigh Optical Scattering (ROS) in an optical fiber backscatters light incident upon the fiber. The incident light transverses down the optical fiber to the scattering point/region. At the scattering region the incident light is backscattered back up the optical fiber. As the light transverses the round trip optical path (i.e., distance of flyback travel) any disturbance of the fiber which increase or decrease the optical path length will cause the phase of the incident and backscattered light to be modulated. Suppose a pressure is applied to the optical fiber. The pressure elongates the path length of the light transversing the region.

[0085]Refer to FIG. 2. for the following discussion. In the FIGS. like parts correspond to like numbers. Let p(t,z) be pressure applied to the outside of the optical fiber at time, t, and at point or length, z, along the fiber axis. Then if an interrogation optical wave, $E_{(i)}(t)$, generated by laser **3**, passed through optical coupler **4** and modulated by optical modulator **5** is applied to optical coupler **7**, this results in the following output interrogation wave, $E_{(i)}(t)$, being transmitted down the fiber **9**: $E_{(i)}(t)=\mu_{(A)}c(t)E_{(ss\ )}$cos(ω$_{(S)}t$). (27)

[0086]The backscattered wave, $E_{(b)}(t)$, arriving back at an optical coupler **7** from ROSE fiber optic array **9** passes into optical path **11**. The backscattered light which arrives at optical path **11** is the summation of all light backscattered from a continuum of locations along the length of the ROSE fiber optic span **9**. As will later herein be described in detail, fiber **9** has a longitudinal strain component enhancing coating **12**. If r(z) is the reflection density at point or length z along the fiber and CL is the optical wave speed, then the backscattered light after a pressure p(t,z) is applied to fiber is represented mathematically as:

[0087]Eb⁡(t)=?0∞⁢r⁡(z^⁡(t,z))⁢µA⁢c⁡(t-2⁢z^⁡(t,z)cL)⁢⁢ESS⁢cos(ωS⁡(t-2⁢z^⁡(t,z)cL)⁢)⁢ⅆz(28) where:

[0088]z^⁡(t,z)=z+µL⁢?0z⁢p⁡(t,x)⁢⁢ⅆx.(29)

[0089]If the distributed reflection, r(z) is essentially independent of the applied pressure, p(t,z) then the backscatter is:

[0090]Eb⁡(t)=?0∞⁢r⁡(z)⁢µA⁢c⁡(t-2⁢z^⁡(t,z)cL)⁢⁢ESS⁢cos(ωS⁡(t-2⁢z^⁡(t,z)cL)⁢)⁢ⅆz.(30)

[0091]Since optical path length change caused by the applied pressure, p(t,z) is usually extremely small (on the order of $10^{(\−6\ )}$to $10^{(1\ )}$times an optical wavelength), the backscattered light from each z distance down the fiber arrives at the optical path **11** with a transversal delay, τ(t,z), equal to:

[0092]τ⁡(t,z)≈2⁢zcL.(31)

[0093]Therefore, to receive the signal $S_{(1\ )}$backscattered from the fiber region at length-down-the-fiber z=$L_{(1)}$, the correlational multiplexing characteristic of the transmitted interrogation light can be utilized. Multiplication of the total backscattered optical signal by the correlation decoding/demultiplexing function, d(t−τ(t,$z_{(1)}$)), produces an output which contains the signal, $S_{(1)}$, backscattered from a distance $L_{(1\ )}$down the fiber and rejects signals originating from other fiber regions, such as $S_{(2)}$, $S_{(n\ )}$and etc. Representing this process mathematically, the resulting channel output, B(t, $L_{(1)}$) is obtained as follows:

[0094]b⁡(t,τ1)=⟨d⁡(t-τ1)⁢Eb⁡(t)⟩=⟨d⁡(t-2⁢L1cL)⁢Eb⁡(t)⟩=B⁡(t,Li)⁢⁢d⁡(t-2⁢L1cL)=µd⁢c⁡(t-2⁢L1cL)⁢EL⁢cos⁡((Δω+ωs)⁢(t-2⁢L1cL)+φ)⁢⁢Eb⁡(t)=?0∞⁢r⁡(z)⁢µA⁢c⁢(t-2⁢zcL)⁢ESS⁢cos⁢⁢(ωs⁡(t-2⁢z^⁢(t,z)cL))⁢ⅆz⁢⁢Φ⁡(z,L1)=φ-2⁢(Δ⁢⁢ω+ωs)⁢LicL+Δ⁢⁢ω⁢⁢2⁢zcL (32)

[0095]B⁡(t,L1)=⁢µd⁢µA⁢EL⁢ESS⁢?0∞⁢r⁡(z)⁢Rc⁡(2⁢(z-L1)cL)⁢cos(Δ⁢⁢ω⁢⁢t+Φ⁢(z,L1)+⁢2⁢µL⁢ωScL⁢?0z⁢p⁡(t,x)⁢⁢ⅆx)⁢⁢ⅆzΔ⁢⁢Φ⁢(t,z)=⁢Φ⁡(z,L1)+2⁢µL⁢ωScL·?0Z⁢p⁡(t,x)⁢⁢ⅆxB⁢(t,L1)=⁢VE⁢?0∞⁢r⁡(z)⁢Rc⁡(2⁢(z-L1)cL)⁢⁢cos⁡(Δ⁢⁢ω⁢⁢t+Δ⁢⁢Φ⁡(t,z))⁢ⅆzB⁡(t,L1)≈⁢VE⁢rL1⁢cos⁡(Δ⁢⁢ω⁢⁢t+ΦL1+2⁢µL⁢ωScL·?0L1⁢p⁡(t⁢,x)⁢ⅆx)(33) Because of the correlation properties of the interrogation light, the autocorrelation function $R_{(c)}$(τ) is very small at all spatial locations except those in the vicinity of z=$L_{(1)}$. Therefore, all signals originating anywhere else are rejected. Furthermore, the phase of the channel output at location $L_{(1\ )}$will be the summation or integration of all pressure changes along the bi-directional transversal path. This unusual phenomenon has been demonstrated with experimental hardware.

[0096]Once the correlation process isolates the optical signal originating from a spatial region, the signal must be phase demodulated to extract the pressure information. The signal is I (in phase) and Q (quadrature phase) demodulated is:

[0097]B1⁡(t,L1)=⁢⟨B⁡(t,L1)⁢cos⁡(Δ⁢⁢ω⁢⁢t)⟩B1⁡(t,L1)≈⁢VE⁢rL1⁢cos(ΦL1+2⁢µL⁢ωScL·⁢?0L1⁢p⁡(t⁢,x)⁢ⅆx⁢)=⁢V1⁢cos⁡(Φ1)BQ⁡(t,L1)=⁢⟨B⁡(t,L1)⁢sin⁡(Δ⁢⁢ω⁢⁢t)⟩BQ⁡(t,L1)≈⁢-VE⁢rL1⁢sin⁡(ΦL1+2⁢µL⁢ωScL·?0L1⁢p⁡(t⁢,x)⁢ⅆx) =⁢-V1⁢sin⁡(Φ1).(34)

[0098]Then I & Q, or cosine phase and sine phase outputs are converted into either phase rate or phase outputs with simple analog or digital hardware. The phase, so demodulated, allows the inference of information about the acoustic pressure down the fiber to the measurement point.

[0099]Once the I & Q outputs are generated, the temporal phase state of B(t, $L_{(1)}$) can be determined by one of several types of phase demodulation processes. The phase state of the region of $L_{(1\ )}$spatial delay is therefore:

[0100]Φ1=ΦL1+2⁢µL⁢ωScL·?0L1⁢P⁡(t,x)⁢⁢ⅆx.(35)

[0101]Likewise, the plurality (which may be a large number, e.g., 5000) of optical signals arising with spatial delays, such as the propagation time for flyback travel to $L_{(2\ )}$or $L_{(n)}$, can be correlated out of the backscattered signal $E_{(b)}$(t). These are:

[0102]B⁡(t,L2)≈VE⁢rL2⁢cos⁡(Δ⁢⁢ω⁢⁢t+ΦL2+2⁢µL⁢ωScL·?0L2⁢p⁡(t⁢,x)⁢ⅆx)⁢⁢B⁡(t,Ln)≈VE⁢rLn⁢cos⁡(Δ⁢⁢ω⁢⁢t+ΦLn+2⁢µL⁢ωScL·?0Ln⁢p⁡(t⁢,x)⁢ⅆx)(36) With corresponding phase signals of:

[0103]Φ2=ΦL2+2⁢µL⁢ωScL·?0L2⁢p⁡(t⁢,x)⁢ⅆx⁢⁢Φn=ΦLn+2⁢µL⁢ωScL·?0Ln⁢p⁡(t⁢,x)⁢ⅆx.(37)

[0104]The phase signals, obtained by phase demodulation of each B(t,$L_{(m)}$), represent a pressure field p(t,z) which is integrated along the length, z, of the fiber. Therefore, rather than directly measure p(t,z) the sensor provides all of the accumulated pressure effects down the fiber to the measurement point, $L_{(m)}$(where m is integer corresponding to the measurement point). In sensor arrays, it is usually desired to detect the pressure over a specific measurement region. If two optical signals $S_{(j)}$and $S_{(k)}$are received from measurement lengths $L_{(j)}$and $L_{(k)}$, the corresponding demodulated phases Φ$_{(j)}$and Φ$_{(k)}$are:

[0105]Φj=ΦLj+2⁢µL⁢ωScL·?0Lj⁢p⁡(t⁢,x)⁢ⅆx⁢⁢Φk=ΦLk+2⁢µL⁢ωScL·?0Lk⁢p⁡(t⁢,x)⁢ⅆx.(38)

[0106]A sensor between the lengths down the fiber of $L_{(j)}$and $L_{(k)}$($L_{(k)}$>$L_{(j)}$) is formed by subtracting the two phases:

[0107]Φk-Φj=⁢Δ⁢⁢Φkj=⁢(ΦLk+2⁢µL⁢ωScL·?0Lk⁢p⁡(t⁢,x)⁢ⅆx)-⁢(ΦLj+2⁢µL⁢ωScL·?0Lj⁢p⁡(t⁢,x)⁢ⅆx)⁢⁢Δ⁢⁢Φkj=⁢ΦLk-ΦLj+⁢2⁢µL⁢ωScL·(?0Lk⁢p⁡(t⁢,x)⁢ⅆx-⁢?0Lk⁢p⁡(t⁢,x)⁢ⅆx)⁢⁢Δ⁢⁢Φkj=ΦLk-ΦLj+⁢2⁢µL⁢ωScL·?LjLk⁢p⁡(t⁢,x)⁢ⅆx⁢⁢Δ⁢⁢Φkj=Δ⁢⁢ΦLk⁢Lj+2⁢µL⁢ωScL·?LjLk⁢p⁡(t⁢,x)⁢ⅆx.(39)

[0108]The resulting sensor is of length ΔL=$L_{(k)}$−$L_{(j)}$with a center position of ($L_{(k)}$+$L_{(j)}$)/2. The differencing of phase signals Φ$_{(j)}$and Φ$_{(k)}$into a new phase signal ΔΦ$_{(kj)}$, allows a virtual sensor of arbitrary position and length to be formed. The resulting spatially differential sensor also adds the advantage of minimizing other effects such as lead-in fiber strum or vibration which create unwanted phase signals.

[0109]The above phenomena illustrates that when the interrogation light is properly encoded, a ROSE (Rayleigh Optical Scattering and Encoding) sensor system is enabled. The subject invention therefore enables the ROSE concept. The subject invention enables spatial discrimination of the optical backscatter effects in a ROSE sensor. The spatial differencing technique rejects unwanted common mode signals inadvertently introduced in fiber leads down to the sensor region. The invention also applies in a similar manner to more conventional fiber optic acoustic sensor arrays (i.e., those having Bragg reflective grating sensors) or to non-fiber optic remote optical sensors which detect phase.

[0110]b. Pointwise Signal Delay Multiplexing

[0111]The invention also applies to point-wise non-distributed sensors or artificially generated multiplexing by electronics means. The interrogation lightwave can be intercepted and retransmitted back to the receiver with an artificial, electronically generated delay, as a means of delay/correlation multiplexing many channels.

(3) Description of a Fiber System Implementation

[0112]The invention can be realized with bulk optical, fiber optical or integrated optical components. For simplicity, a fiber optic implementation will be presented. However, the fiber optic embodiment is being presented without intent of limitation. The teachings of the invention can be used to implement a reflectometer system in accordance with the present invention using these and other instrumentalities providing a light path that has the innate property of producing back propagation of portions of an interrogation signal at a continuum of locations along the length of the propagation path therethrough.

[0113]a. Optical Transmitter and Time-Delay Multiplexing Process.

[0114]FIG. 3 is an illustrative block diagram implemention of the Rayleigh optical scattering and encoding (ROSE) sensor system **2**. Like parts correspond to like numbers. A lightwave from transmitter laser, **3**, is propagated through optical coupler or beamsplitter, **4**. The smaller portion of the transmitter laser power split off by optical coupler, **4**, is passed by optical path, **39**, to the phase locking means optical receiver **35**. The larger portion of the transmitter laser light power is split by optical coupler, **4**, and propagated to optical modulator, **5**. The optical modulator, **5**, modulates the laser light passing from optical coupler, **4**, with correlation code, c(t), as electronically generated in master correlation code generator, **53**, and amplified by amplifier, **49**. The correlation code, c(t), is modulated onto the laser light in optical modulator, **5**. This modulated light comprises the optical interrogation lightwave, $E_{(i)}(t)$. The optical modulator, **5**, may modulate the amplitude, polarization or phase of the laser light subject to the teachings of the invention. The interrogation lightwave is propagated from optical modulator, **5**, to optical coupler, beamsplitter or circulator, **7**. The interrogation lightwave passes through the optical coupler, **7**, into optical fiber or other light propagation medium, **9**. Hereinafter, "down", indicates a transversal on the optical path, **9**, away from coupler, **7**; "up" indicates a transversal on the optical path **9** toward the optical coupler, beamsplitter or circulator, **7**. The interrogation lightwave which transverses down the optical fiber or medium **9** is modulated and is backscattered or returned by other means with equivalent optical path lengths (equivalent to a time delay), $L_{(1)}$, $L_{(2)}$. . . $L_{(n)}$corresponding to sensors or multiplexed channels $S_{(1)}$, $S_{(2)}$. . . . $S_{(n)}$. The returned interrogation lightwave is a composite optical signal modulated by signals due to the $S_{(1)}$through $S_{(n)}$modulating and time-domain multiplexing actions.

[0115]More particularly, the propagation of the optical spread-spectrum interrogation signal down the continuous full span of the optical fiber span, signal launch end to remote end, causes a back-propagating composite optical signal, which is the linear summation, or integration spatially, of all of the individual, continuous, or continuum of back-reflections along the span of the optical fiber.

[0116]One component of this composite signal is comprised of the naturally occurring continuum of optical back reflections (including Rayleigh optical scattering ((ROS)) effects) of the optical spread spectrum carrier signal that is formed by modulating the primary carrier signal by the spectrum spreading signals. Another component is comprised of the artificially occurring optical back reflections, either-point wise reflections or distributed reflections, of the optical spread spectrum carrier signal that is formed due to propagation discontinuities as the result of presence of a fiber cable coupler in span **9**. Still another component comprised of the continuum of modulations at locations along the span of the reflected signals due to longitudinal components of optical path length change, causing a delay in the reflected signal, experienced by the fiber optical span along its length.

[0117]Such optical path length change or delay may be caused by a variety of possible sources including acoustic pressure waves incident to the fiber, electromagnetic fields coupled to the fiber, mechanical strain or pressure on the fiber, thermal strain or pressure induced in the fiber, or other means of causing change in the optical path length. Use of the acoustic pressure waves mode of changing path length in perimeter intrusion monitoring systems is the principle embodiment illustrated herein. In this use, optical fiber span **9** is employed to provide an array of virtual geophones buried at a range of depths beneath the surface of the ground of about between six (6) inches and one (1) foot, to sense motion of an object on the surface of the ground. The acoustic pressure wave sensing mode is also useful to sense seismic signals, as for example as linear arrays inserted into casing structures of an existing oil wells. Predetermined artificial pressure wave producing shocks are imparted into the ground, and the responses from the sensor are used to locate secondary oil deposits. The acoustic pressure wave sensing mode is further useful for employing span **9** as an array of virtual hydrophones, with the media which couples the signals to the hydrophones at least in part being the body of water in which the array is immersed. Such hydrophone arrays find use as naval undersea warfare towed arrays, or towed geophysical exploration arrays. In the latter the arrays respond to artificially produced shocks of predetermined character and location induced in the body of water, and the response of the array to bottom return signals are used to locate ocean bottom geophysical feature indicating likely presence of an oil deposit. Yet further, a sensing position on a fiber span **9** could be used to receive as an input microphonic signals suitably imparted to the region of the sensing position. The electromagnetic field sensing mode of fiber span **9** could be used for monitoring electronic signals along a telecommunication cable's span to localize malfunctions. Responses of fiber span **9** to mechanical, pressure or thermal strains can be used in systems for monitoring such strains.

[0118]The composite lightwave propagates up the optical fiber or medium **9**, passes through optical coupler, beamsplitter or circulator, **7**, to optical pathway, **11**. Optical pathway, **11**, passes the backscattered, time-delay multiplexed, composite lightwave, $E_{(b)}(t)$, to the optical receiver, **15**.

[0119]Preferably, fiber **9** is of the relatively low cost, conventional single-mode or multimode, fiber cable types.

[0120]Further it is preferable that fiber **9** have extruded thereon a coating **12** of a material which enhances the longitudinal strain which the fiber undergoes from a given radially, or generally laterally, applied pressure wave strain. Materials which provide such enhancement include extrudable thermoplastic polymers (TPU's) or extrudable thermoplastic elastomers (TPE's) which exhibit a combination of a low Young's modules (E) and a low Poisson's ratio (s). The Poisson's ration is preferably below 0.5, which is the Poisson's ratio of natural rubber. Examples of such materials include: (i) low density polyethylene, having characteristic E=1.31 dynes/cm$^{(2)}$×10$^{(\text{\−}10\ )}$and s=0.445; and (ii) polystyrene, E=3.78 dynes/cm$^{(2\ )}$and s=0.35 (values as reported in the paper, R. Hughes and J. Javzynski, "Static Pressure Sensitivity Amplification in Interferometric Fiber-Optic Hydrophones," Applied Optical/Vol. 19/No. 1/1 Jan. 1980).

[0121]An alternate embodiment of fiber **9**, albeit involving significantly greater cost per unit length of the fiber, is to provide fiber in the more expensive form of a polarization preserving or single polarization, optical fiber. The polarization preserving fiber of this type holds the backscattering light in a narrow range of polarization states so that a substantially single RF signal **21** enters a single set **23** of correlators, reducing the complexity of the system. However, in cases involving long surveillance lines this alternative embodiment becomes expensive in cost of fiber.

[0122]The correlation code generator **53** creates a signal, c(t), that has a broad bandwidth. The broadband nature of the correlation code is required to obtain the desired properties in the signals autocorrelation function. The calculation and definition of the autocorrelation function of any general signal is well known and defined in signal processing literature. The correlation code signal, c(t), is so structured that its autocorrelation function is highly peaked at zero delay, and is very small away from zero delay. This criterion is well known to those of skill in the art and is the essence of why the correlation code has a broad bandwidth. Any signal that has the desired autocorrelation function properties can be used as the correlation code in the invention. There are many reasons for choosing one correlation code over another: ease of creation; autocorrelation properties; cost of creation hardware; cost of correlation hardware; and effectiveness in producing spread spectrum signal effects. According to the teaching of the invention, the correlation code for the invention can be a binary sequence with a desired transorthogonal autocorrelation property (sometimes called a pseudonoise sequence), a pseudorandom number (PRN) sequence with the such desired autocorrelation property, chirps, or other types of signals which provide correlations code having predicable non-repetitive behavior. The foregoing list of types of sequence signals which may be employed to modulate the carrier lightwave signal includes both "binary pseudonoise sequences" and "pseudorandom number (PRN) sequences." For purposes of construction of this specification and the appended claims, these terms are employed as they are defined under the listings "Pseudonoise (PN) sequence (communication satellite)" and "Pseudorandom number sequence" at pages 747 and 748 of the "IEEE Standard Dictionary of Electrical and Electronic Terms" (Fourth Edition), which listings are hereby incorporated herein by reference. Further for purposes of construction of this specification and the appended claims, it is deemed that "binary pseudonoise sequence" is generic and "pseudorandom number sequence" is a species thereof. Still further for purposes of construction of this specification and its appended claims, both terms are deemed to include analog signal forms of sequences as well as digital signal forms.

[0123]It is to be appreciated that in addition to its correlation encoding function, master correlating code generator **53** is a source of a spectrum-spreading signal comprised of a spectrum-spreading signal which produces an autocorrelation that is well behaved. It has one dominate maxima at zero correlation delay, and its spectrum is large enough to provide sampling of the said optical fiber spatially along the length of the fiber **9** with a resolution commensurate with a sub-length ΔZ of fiber span **9**. These characteristics enable segmentation of an optical fiber **9** of span length L into n segments in accordance with a relationship L<ΔZ·n. (40) In this relationship ΔZ is a segment length of the fiber span whose length is one-half the distance traveled by light propagating through one zero delay temporal time span of the autocorrelation maxima, ΔT, such that $C_{(L\ )}$is the speed of light in the said optical fiber and ΔT is approximately equal to the reciprocal of the spread signal optical bandwidth.

[0124]An illustrative embodiment of generator **53** is a shift register type pseudorandom number code generator, having n bits, wherein a code is generated that satisfies said resolution sublength and segment length relationship by choosing an appropriate combination of the number of its bits and the clock time.

[0125]The temporal length of the code sequence which is reiteratively produced by generator **53** may be either less than the time period for propagation of a lightwave to the remote end of span and propagation back of a backscattering (i.e. distance of flyback travel), or greater than this time period. It cannot be equal to this period.

[0126]The predetermined timing base employed by the source of the spectrum spreading signals, which determines the length of ΔZ segment is so chosen to provide a positive enhancement to the ratio of the power of back propagating Rayleigh scattering effect $P_{(R)}$to the power of the forward propagated Rayleigh scattering effect $P_{(T)}$, in accordance with the following equation:

[0127]PrPt⁡[dB]=-70+10⁢log10⁡(Δ⁢⁢L)-Δ⁢⁢Z100.(41)

[0128]b. Laser Phase Locking Means.

[0129]Refer to FIG. 3. Local oscillator laser, **45**, generates a local oscillator lightwave. The local oscillator lightwave propagates from local oscillator laser, **45**, to optical coupler or beamsplitter, **43**. The optical coupler, **43**, splits off the smaller portion of power of the local oscillator lightwave into optical pathway, **41**. Optical path, **41**, propagates the smaller portion of the local oscillator lightwave to the phase locking means optical receiver, **35**. The larger portion of the power of the local oscillator lightwave is split off by optical coupler **43**, and passed to optical path **13**. Optical pathway, **13**, propagates the larger portion of the local oscillator lightwave to optical receiver, **15**. The phase locking means optical receiver, **35**, receives and interferes the transmitter laser lightwave from optical pathway, **39**, and the local oscillator lightwave from optical pathway **41**. The receiver **35** interferes the reference lightwaves from lasers **3** and **45** producing an electrical output which is a radio frequency wave on electrical pathway, **33**. The electrical output, **33**, provides an electronic beat frequency which directly indicates the difference in optical frequency and phase between lasers **1** and **45**. Phase locking circuitry **31**, employing a conventional phase lock loop mechanism, controls the difference in frequency between laser **1** and **45** and phase locks the two lasers to a fixed frequency and phase relationship as indicated by the dashed line between circuitry **31** and local oscillator laser **45**. The radian frequency difference is Δω as discussed early in the text. The purpose of the laser phase locking means is to insure that the local oscillator lightwave traveling on optical path, **13**, into optical receiver, **15**, has the proper phase and frequency relationship to the composite lightwave on optical pathway, **11**. It is to be appreciated that the phase locking mechanism also acts cooperatively with phase demodulator system **66** to be described later herein. Conventionally, a common master clock oscillator **311**, FIG. 7 provides the timing base for both phase locking circuitry **31** and an I & Q demodulator **300**, FIG. 7.

[0130]Refer to FIG. 3. The composite lightwave on optical path **11**, is an input into optical receiver **15**. The local oscillator lightwave on optical path, **13**, is also an input into optical receiver, **15**. The local oscillator and composite lightwaves are interfered on photodetectors producing an electronic signal which electronically represents the heterodyned optical interference power between the two lightwaves. The resulting composite radio frequency signal at output, **17**, represents electronically the composite lightwave signal on optical path, **11**. The composite electronic receiver signal is passed from optical receiver output, **17**, through amplifier, **19**, via electronic path, **21**, to the correlator system, **23**. The local oscillator lightwave on optical path, **13**, is interfered with the composite lightwave on optical path **11**. The interference power is photodetected in optical receiver, **15**, by optically interfering the composite back propagating lightwave on the local oscillator signal. As one of the components of this interfering action, there is produced a difference beat signal which is a composite radio frequency representation of the composite light wave on optical path, **11**.

[0131]This interfering of the local oscillator output lightwave **13** and the composite back-propagating CW lightwave **11** provides the translation of signal **11** from the optical domain to a CW radio frequency (r.f.) composite difference beat signal **17**. This reduces the frequency of signal **15** into an electronically processable signal frequency range. It is to be appreciated that an important aspect of the present invention that the r.f. composite difference signal produce by this translation action includes having counterpart components of the aforesaid components of the composite back-propagating lightwave signal, with the phase states of these counterpart r.f. domain signals the same as the phase states of the corresponding components of the back-propagating lightwave.

[0132]In accordance with the present invention, lasers **3** and **45** are to have sufficiently stringent high performance capability with respect to exactness of frequency to enable interference effects therebetween and heterodyne detection of acoustic perturbation signals incident to fiber **9** to produce beat frequencies within the radio frequency (r.f.) range. Also in accordance with the present invention, lasers **3** and **45** have stringent performance criteria with respect to the phase stability, or coherence, of their beams. They are to be substantially coherent over at least a propagation path distance substantially equal to twice the length, L, of sensing fiber **9**. For example, a commercially available non-planar, ring laser (e.g. Lightwave Electronics Corp. Model 125) would be suitable for an intruder sensing perimeter intrusion monitoring fiber **9** having a length of 8.0 km (approximately 5 miles). The laser beam of this commercially available laser, which is in the near infrared range, has a frequency of 227 terahertz, or 1319 nanometer wavelength, and has a frequency stability accurately within one part in a billion over 1 millisecond period, or 5 Kilohertz in a 1 millisecond period.

[0133]It is to be appreciated that the provision of such frequency and phase stability of lasers **3** and **45** enables implementing the phase locking to produce a sufficiently small non-zero radian phase locking circuitry **31**. This in turn enables lasers **3** and **45**, under regulation by phase locking circuitry **31**, to provide a pair of beams which are phase locked and with a "non-zero Δω" sufficiently small to enable a heterodyne-mode optical receiver to provide the desired beat frequency outputs in the r.f. range. It is understood that laser **45**, optical receiver **35**, circuitry **31** and beamsplitter **43** could be replaced with an apparatus applying the non-zero ΔW to the beam from optical pathway **39** to give the same result. The returned interrogation optical composite wave is defined in the preceding subsection **3**(*a*) "Optical Transmitter and Time-delay Multiplexing Process" of this DESCRIPTION OF THE PREFERRED EMBODIMENT.

[0134]In the preceding section (1) "Description of Underlying Theories" of this DESCRIPTION OF THE PREFERRED EMBODIMENT there is a definition of "non-zero Δω" and a mathematical demonstration of its importance in the heterodyne mode of interfering. It makes it possible to use relatively simple processes to avoid fading. By way of contrast, fading with the "zero Δω" homodyne mode of interfering would entail much more difficult and less effective fade avoidance processes.

[0135]c. Correlation Time-Delay Demultiplexing.

[0136]Refer to FIG. 3. The composite radio frequency signal on electrical path, **21**, is input into the correlator system, **23**. The correlator system delays the master correlation code generator output, **51**, an appropriate amount and correlates the delayed correlation code with the composite radio frequency signal. This produces electrical outputs $O_{(1)}, O_{(2)}$. . . $O_{(n)}$ corresponding to signals $S_{(1)}, S_{(2)}$. . . . $S_{(n)}$, in turn corresponding to spatial delays $L_{(1)}$, $L_{(2)}$. . . $L_{(n)}$. The spatial delays $L_{(1)}, L_{(2)}$. . . . $L_{(n)}$ are arbitrary and programmable. The electrical output $O_{(1)}$ corresponds to $B(t, L_{(1)})$ referred to in the preceding subsection **2**(*a*).

[0137]The correlation process is well understood in the literature. The signal that represents the backscattered optical wave in array, **9**, that is passed from the optical receiver **15**, to the correlator system **23**, contains all of the information for all sensors or channels $S_{(1)}, S_{(2)}$. . . . $S_{(n)}$ at once on the electronic signal path **21** entering the correlator **23**. Because the backscattered composite signal is modulated with the correlation code by modulator **5**, the backscattered light is time structured with the time structure of the correlation code. Because the correlation code is selected to have special autocorrelation code properties, the time structure of the correlation codes allows an electronic representation of the backscattered light at positions $L_{(1)}, L_{(2)}$. . . . $L_{(n)}$ to be obtained via the correlation process in the correlator **23**. In a preferred embodiment of the invention the master code generator **53** is a shift register type pseudorandom number (PRN) code generator and each correlator of the set **23** would be a correlation type demodulator herein later described in greater depth. Code generator **53** may alternatively be embodied as a binary sequence having transorthogonal autocorrelation properties (binary pseudonoise sequence) and each correlator would then be a correlation-type demodulator for demodulating a binary pseudonoise sequence, whose implementation would be understood by those of skill in the art. The correlator uses the reference correlation code from correlation code generator, **53**, which is passed via electronic path **51** to the correlator, **23**, as a "golden ruler" enabling sorting out by temporal and spatial domain demultiplexing electronic representations of the backscattering optical signals at sensors or channels $S_{(1)}, S_{(2)}$. . . $S_{(n)}$. Various delayed versions of the correlation code are multiplied by the composite signal with all of the sensor or channel signals present simultaneously, from electronic path **21** so that the electronic representations of the sensors or channels $S_{(1)}, S_{(2)}$. . . $S_{(n)}$ are output from the correlator, **23** on signals $O_{(1)}, O_{(2)}$. . . $O_{(n)}$ with respect to the index.

[0138]Correlator system **23** is an electronic spread spectrum signal de-spreader and temporal and spatial domain de-multiplexer of the r.f. signal counterpart to the optical composite signal. Its input is coupled to the amplified output **21** of the heterodyner and photodetector, and it is operative in cooperation with said source of spectrum spreading signals to perform a coherent signal correlation process upon the r.f. counterparts of the aforesaid "one" and the aforesaid "still another" components of the composite back-propagating CW lightwave. This causes the de-spreading of the r.f. counterpart of the optical reflected spread spectrum signal and causes the temporal and spatial demultiplexing of the r.f. counterpart of the "still another" component of the composite r.f. signal. This processing provides signals which temporally and spatially sort the said "still another" component into n virtual sensor signal channels, or stated another way n of each of the ΔZ length measurement regions, measuring the induced optical path change at each of the n ΔZ-length segments of the optical fiber span **9**.

[0139]It will be appreciated that this sorting process is accomplished by the autocorrelation properties of the spectrum-spreading signal and by the time of flight of the optical spectrum-spreading signal down to each nth reflection segment and back to the heterodyne optical receiver **15**. A delayed replica of the spectrum-spreading signal is correlated against the r.f. signal counterpart of the optical composite back-propagating signal, thereby segmenting the optical fiber into n independent segments, or virtual sensors, via the time of flight of the optical composite back-propagating signal and the autocorrelation function of the transmitted spectrum-spreading signal.

[0140]It is to be appreciated that system **2** is operating in the spread spectrum transmission and reception mode. Namely, by providing optical interrogation light wave, $E_{(1)}(t)$, with modulation by the correlation code, c(t), the continuous wave carrier signal is temporally structured into a spread spectrum interrogation lightwave which continuously reiterates autocorrelatable code sequences. Then after correlation system provides an appropriate time of delay the correlator system **26** correlates the backscattered light wave $E_{(b)}(t)$ with the same output, c(t), of code generator **53**, de-spreading the spread spectrum signal.

[0141]In accordance with well known communication electronics theory this has the effect of increasing signal output of the ROSE sensor system while the noise bandwidth remains the same. In temporally and spatially sorting the r.f. counterpart of the aforesaid "still another" component of the composite back-propagation lightwave, the aforesaid "another" component of undesired noises, such as reflections from couplers in fiber span **9**, are materially attenuated.

[0142]More particularity, in accordance with this well known theory, the signal-to-noise ratio (SNR) is enhanced by considerable attenuation of noise mechanisms in frequency ranges outside of center frequency lobe of the autocorrelation function and outside the pair of first side lobes to one and the other side of the center frequency lobe.

[0143]An illustrative embodiment of electronic spread spectrum signal de-spreader and spatial de-multiplexer for cooperation with the previously described shift register type PRN code generator may comprise a series of n like-shift register code generators respectively receiving the spectrum spreading signal through a corresponding series of n feed channels which cause delays which incrementally increase by an amount of time bearing a predetermined relationship to the fiber span length, and $C_{(L)}$, the speed of light through the fiber. The composite r.f. signal is fed to a corresponding series of n multipliers connected to receive as the other multiplier the codes generated by the respective de-spreader and demultiplexer to thereby provide the de-spread and de-multiplexed signal.

[0144]d. Heterodyne Phase Demodulation.

[0145]Refer to FIG. 3. After the composite radio frequency signal on electrical path **21** is correlation time-delay demultiplexed by the correlator system, **23**, the plurality (which upwardly may include a very large number, for instance 5,000) of outputs $O_{(1)}$, $O_{(2)}$. . . $O_{(n)}$, on the plurality of electrical paths **61**, **63** and **65** respectively are phase demodulated by a plurality of individual phase demodulations in the phase demodulator system, **66**. The outputs of the phase demodulator system, **66**, are the corresponding plurality of electrical paths **71**, **73**, and **75**. The phase demodulator outputs **71**, **73**, and **75** correspond to the correlator outputs ($O_{(1)}$, $O_{(2)}$. . . $O_{(n)}$) **61**, **63** and **65** respectively, and to the corresponding plurality of corresponding signals $S_{(1)}$, $S_{(2)}$. . . $S_{(n)}$respectively corresponding to spatial delays $L_{(1)}$, $L_{(2)}$. . . $L_{(n)}$respectively. The outputs **71**, **73**, and **75** electronically indicate (with tens of kilohertz potential bandwidth) the phase states of optical signals $S_{(1)}$, $S_{(2)}$. . . $S_{(n)}$. In particular, output **71** is proportional to the temporal phase Φ$_{(1)}$of B(t, $L_{(1)}$) hereinbefore discussed in subsections 1(b) "Correlation or Time-delay Multiplexing" and 3(c) "Correlation Time-Delay Demultiplexing" of this DESCRIPTION OF THE PREFERRED EMBODIMENT. The phase demodulator outputs **73** and **75** indicate the temporal phase states Φ$_{(2)}$and Φ$_{(n)}$of B(t,$L_{(2)}$) and B (t,$L_{(n)}$) respectively.

[0146]e. Fading Free Polarization Processing

[0147]Preferably system **2** further includes polarization signal characteristic processing functions (not shown), which are used together with the previously described feature that the heterodyning function provides in reducing fading, of the backscattering signal, $E_{(b)}(t)$. These polarization processing functions are disclosed in the commonly assigned U.S. Pat. No. 6,043,921 entitled "Fading-Free Optical Phase Rate Receiver," hereby incorporated herein in its entirely. The optical heterodyning feature which provides benefit in reducing fading includes: (i) cooperation of phase locked lasers **3** and **45** in the formation of the optical interrogation light wave, $E_{(1)}(t)$, applied to optical fiber **9**, or other linearly extended light propagation medium producing Rayleigh effects backscattering, and (ii) the manipulation of this by optical receiver **15** to provide the composite electronic receive signal as optical receiver output **17**. This takes advantage of the feature of more favorable Heterodyne fading conditions in a way, in which polarization and phase state signal fading is materially reduced in the detected backscattered light wave $E_{(b)}(t)$. The electronic decoding module 700 of U.S. Pat. No. 6,043,921 is substantially an equivalent to the correlator system herein. However, the system disclosed in U.S. Pat. No. 6,043,921 for implementing polarization fading reduction (if not substantially eliminating fading) is a generalized stand alone system for processing any optical phase signal having temporally varying polarization, phase, and phase frequency. It must be adapted for application to system **2** by appropriate integration into system **2** included the two following alternative approaches.

[0148]One approach for such adaptation passes the fade-free optical phase rate (FFOPR) photoreceiver RF signal to the correlator **23**, performs the correlation on the RF signal and completes the Phase Demodulation by In phase and Quadrature phase (hereinafter I & Q) demodulating the correlated RF signal into outputs. This method creates low bandwidth I & Q components and therefore requires low bandwidth analog-to-digital converters (implying a requirement for a large number of analog RF correlation electronic components). This RF correlator approach requires two correlator circuits for every virtual sensor element, or spatial channel, along fiber **9**. One correlator is needed for the vertical polarization RF signal path and one correlator is needed for the horizontal polarization RF signal path.

[0149]Another approach applies the I & Q demodulator of FIG. 7 of the U.S. Pat. No. 6,043,921 prior to correlation. This approach therefore correlates a wideband set of four I & Q signals. One I, Q, set is for horizontal polarization and the other I, Q, set is for the vertical polarization. In this case the I & Q signals are the I & Q signals for the whole virtual array rather than for one virtual sensor element of the array. Four correlators are required for each sensor element. One correlator is applied to each of the four wide bandwidth I & Q signals for each virtual sensor element. This second approach requires very wideband analog-to-digital converters, but allows digital correlators to be used instead of analog RF correlators. The RF correlator or first approach requires far more analog to digital converters and RF electronics. The digital correlator approach enables the correlators to be implemented by the digital approaches of massively integrated logic circuits and/or programmed processors, requiring far more digital logic, but substantially reducing the r.f. electronics and number analog-to-digital converter units in the system.

[0150]f. Phase Differencing

[0151]Refer to FIG. 3. The plurality (which upwardly may include a very large number, for instance 5,000) of signals indicating the phase states Φ$_{(1)}$, Φ$_{(2)}$. . . Φ$_{(n)}$on electrical paths **71**, **73** and **75**, respectively, are input into the phase differencer, 99. The phase differencer forms a corresponding plurality of outputs **91**, **93** and **95** which are arbitrarily and programmably assigned as the subtractions of any two pairs of phase signals Φ$_{(j)}$and Φ$_{(k)}$(where j and k are selected from 1, 2 . . . n).

[0152]Each of the programmably selectable pairs of differenced phase signals form a signal ΔΦ$_{(kj)}$which is spatially bounded within the region of the fiber between lengths $L_{(j)}$and $L_{(k)}$. The phase differencer therefore produces differential phase outputs corresponding to a set of programmable length and position virtual sensors.

[0153]Stated another way, each programmable selection of pairs of phase signals forms a virtual spatial differential sensor which senses the difference between the phases of the Δω output of the photodector sub-system (which is the subject of the next subsections) in receiver **15**. Each Δω is an r.f. difference beat signal representative of the aforesaid “still another” component of the composite back-propagating CW lightwave signal which passes from the launch end of fiber span **9** to directional coupler **7**. These signals from each pair therefore represent signals of virtual spatial differential sensors along fiber span **9**. As a result of the choice of pairs being selectively programmable these virtual sensor can be employed to implement adaptive apertures in processing signal incident the fiber span. This feature would be useful, for example, in enabling security system operators to classify objects causing acoustic pressure wave signals incident up a fiber span **9** used as a perimeter intrusion monitoring line.

[0154]g. Optical Detector Sub-System.

[0155]The optical receivers **15** and **35**, FIGS. 3, 4 and 5, are comprised of photodetector sub-systems. Any of the many well known photodetecting techniques and devices may be employed. Possible implementation of the photodetection sub-systems will now be discussed.

[0156]Refer to FIG. 4. Like parts correspond to like numbers. Optical signals enter the photodetector sub-system via optical paths **101** and **103** which are extensions of the paths **11** and **13** in the case of receiver **15**, and (not shown) of paths **39** and **44** in the case of subsystem **35**. The optical signals are equally split by optical coupler or beamsplitter, **105**. The optical signal on path **107** is composite signal comprised of half the optical power of path **101** and half of the optical power arriving on pate **103**. The optical signal on path **107** is illuminated on optical detector **111**. The photo-current of optical detector **111** flows into electrical conductor **115**. Likewise, the optical signal on path **109** is comprised of half the optical power on path **101** and half of the optical power on path **103**. The optical signal on path **109** is illuminated on optical detector **113**. The photo-current of optical detector **113** flows out of electrical conductor **115**. Therefore the photo-currents of optical detectors **111** and **113** are subtracted at electrical conductor or node **115**.

[0157]Photo-detectors **111** and **113** are precisely matched in responsivity. The differential photocurrent on electrical conductor **115** is input into pre-amplifier **117**, amplifier and is passed to electrical output **119**. The differential nature of the photo-detection rejects either of the self-optical interference power of the signals on paths **101** and **103** and receives only the cross-interference power between the two optical signals on paths **101** and **103**. This particular optical detector architecture is called a balanced heterodyne optical detection scheme. The scheme is 3 dB more sensitive than all other heterodyne optical detection methods and offers the distinct advantage of rejecting local oscillator noise.

[0158]Refer to FIG. 5. FIG. 5 illustrates an alternative photo-detection scheme to FIG. 4. lightwaves enter the receiver at paths **101** and **103**. The optical coupler or beamsplitter **105** combines the lightwaves on paths **101** and **103** into a composite lightwave on path **107**. The composite lightwave on path **107** illuminates optical detector **111**. The photo-current of optical detector caused by the self-interference and cross interference of lightwaves originating from optical paths **101** and **103** passes through conductor **115***a*, is amplified by pre-amplifier **117** and is passed to electrical output **119**.

[0159]The optical detector sub-system of FIGS. 4 and 5 correspond to optical receivers **15** or **35** of FIG. 3. Paths **101** and **103** correspond to **11** and **13** and output **119** corresponds outputs **17** in optical receiver **15**. Paths **101** and **103** correspond to **39** and **41** and output **119** corresponds to output **33** in optical receiver **35**. Either of the photo-detection schemes of FIG. 4 or **5** can be used for the optical receivers **15** or **35**. However, the photodetection scheme of FIG. 4 is preferred.

[0160]h. Programmable Correlator System

[0161]Refer to FIG. 6. The composite radio frequency signal, or r.f. composite reference beat signal, which electronically represents the received time-delay multiplexed optical signal, or composite back-propagation CW lightwave, $E_{(b)}(t)$, is input into the correlator system, **23**, at electrical input **21**. The composite radio frequency signal is n-way split with power splitter **203** into a plurality (which upwardly may include a very large number, for instance 5,000) of electronic pathways including **211**, **213** and **215**. The master correlation code, c(t), is input into the correlator system, **23**, at electrical input **54**. The correlation code is distributed to such a plurality of programmable delay circuits including **221**, **223** and **225**. Each programmable delay circuit delays the master correlation code by the delay required to decode/demultiplex each time-delay multiplexed channel. The plurality of programmable delay circuits including **221**, **223** and **225** output a plurality of delayed correlation codes including those on electrical pathways **231**, **233**, and **225** respectively. The corresponding plurality of delayed correlation codes including those on electrical pathways **231**, **233** and **235** are multiplied by a corresponding plurality of multipliers (or balanced mixers) including **241**, **243** and **245**, respectively, by the radio frequency signal on the plurality of electronic pathways including **211**, **213** and **215** which are amplified by a corresponding plurality of amplifiers including **261**, **263** and **265**, respectively, to produce the corresponding plurality of outputs including $O_{(1)}$, $O_{(2)}$, and $O_{(n)}$ (on lines **61**, **63** and **65**) respectively. Each of the outputs therefore produces the corresponding demultiplexed signal which is time-gated by the corresponding time-delay of the correlation code. The correlator system **23** of FIG. 6 is an example implementation of the correlation system, **23**, of FIG. 3.

[0162]The output $O_{(1)}$ corresponds to signal $B(t,L_{(1)})$ which is hereinbefore discussed in subsections 2(a) "ROSE Optical Phase Sensor Interrogation Enables Sensor System" and 3(c) "Correlation Time-Delay Demultiplexing" of this DESCRIPTION OF THE PREFERRED EMBODIMENT. The output $O_{(1)}, O_{(2)}, \ldots O_{(n)}$ on lines **61**, **63** and **65**, respectively, correspond to signals $S_{(1)}, S_{(2)}, \ldots S_{(n)}$ which in turn are based upon the spatial delay associated with distance $L_{(1)}, L_{(2)}, \ldots L_{(n)}$ indicated in FIG. 3. These spatial delays are based on the time of propagation for flyback travel along these distances, which are arbitrary and programmable. The time delay multiplexing of the optical signals comprising the composite back-propagating optical signal on path **11**, FIG. 3, arise from a plurality (which upwardly may include a very large number, for instance 5,000) of spatial locations causing a like plurality of time-delays. The correlator system spatially separates the components of the r.f. composite difference beat signal into channels which each uniquely represent an optical signal at a single spatial location.

[0163]The correlator system allows the spatial sampling of the optical signals so that a virtual array can be formed along the fiber span **9** on FIG. 3.

[0164]i. Phase Demodulation System

[0165]The embodiment of phase demodulator system, **66**, of FIG. 3, has two uses in system **2**. It either: (i) receives the outputs of the just described r.f. correlator subsection **23**, or (ii) is part of the integration of the polarization fading reduction system of U.S. Pat. No. 6,043,921 (as discussed in the preceding subsection 2(*e*) "Fading-Free Polarization Processing" of this DESCRIPTION OF THE PREFERRED EMBODIMENT. Refer to FIG. 7. The phase demodulation system, **66**, is comprised of a plurality (which upwardly may include a very large number, for instance 5,000) of phase demodulators, **81**, **83** and **85**. The inputs to the plurality of phase demodulators, **61**, **63** and **65** (the correlator outputs $O_{(1)}, O_{(2)}, \ldots O_{(n)}$ discussed previously) are phase demodulated with phase demodulators **81**, **83** and **85** respectively. The outputs of these demodulators are passed on electrical pathways **71**, **73** and **75** respectively.

[0166]Refer to FIG. 8. An example block diagram of any one of the just discussed phase demodulators **81**, **83** and **85** is shown as part **300**. The input electrical path **301** corresponds to any one of electrical path **61**, **63**, **65**, etc. of the plurality of phase demodulators. The output electrical path **319** corresponds to any one of electrical path **71**, **73**, **75**, etc. of the plurality of phase demodulators. A correlation system output such as $O_{(1)}$, $O_{(2)}$ or $O_{(n)}$ is passed via electrical path **301** into a bandpass filter **303**. The bandpass filter **303** passes only a band of radian frequencies in the vicinity of Δω so that only $B(t,L_{(m)})$ passes through the filter (where m is an integer corresponding to the particular channel). The band passed signal passes from **303** via electrical path **305** to amplitude control **307**. Amplitude control **307** is either an analog automatic gain control circuit, an electronic clipper circuit, or a combination thereof. The amplitude control **307** removes amplitude variations due to polarization fading or other types of signal fading. Because the signal, $B(t,L_{(m)})$ is a result of a heterodyne interference, the phase remains the same after clipping. It is to be appreciated that other phase demodulation schemes for fiber optic signals use a phase carrier technique which does not allow the clipping operation. Clipping is a preferred amplitude control mechanism. The amplitude control **307** passes an amplitude stabilized signal via electrical path **309** to I & Q demodulator **311**. The I & Q demodulator removes the carrier, that is it shifts the center radian frequency of the amplitude stabilized $B(t,L_{(m)})$ from Δω down to zero. The I & Q demodulator outputs a voltage proportional to cos(Φ$_{(m)}$) on electrical path **313** and a voltage proportional to sin(Φ$_{(m)}$) on electrical path **315**. The cos(Φ$_{(m)}$) and sin(Φ$_{(m)}$) proportional voltages on electrical paths **313** and **315** respectively are converted in an output signal proportional to Φ$_{(m)}$ on electrical path **319** by the phase detector **317**.

[0167]Reviewing the previous discussion, the plurality of phase demodulators **81**, **83** and **85** of FIG. 7 each function like the block diagram of **300** on FIG. 8. The plurality (which upwardly may include a very large number, for instance 5000) of phase demodulators **300** convert to a like plurality of signals $B(t,L_{(1)})$, $B(t,L_{(2)}) \ldots B(t,L_{(n)})$ into a like plurality of signals proportional to Φ$_{(1)}$, Φ$_{(2)}$. . . Φ$_{(n)}$ which correspond to optical signals $S_{(1)}, S_{(2)}, \ldots S_{(n)}$.

[0168]j. I & Q Demodulator.

[0169]An example implementation of the I & Q demodulator **311** of FIG. 8 will now be presented. Refer to FIG. 9. An amplitude stabilized $B(t,L_{(m)})$ signal (originating from the amplitude control **307** of FIG. 8) is passed on electrical path **309** to a power splitter **403**. Half of the signal power exiting from power splitter **403** is passed to analog mixer, balanced mixer, Gilbert cell or analog multiplier **413** via electrical path **411**. The other half of signal power exiting form power splitter **403** is passed to analog mixer, balanced mixer, Gilbert cell or analog multiplier **423** via electrical path **421**.

[0170]The reference oscillator **451** generates an electronic wave proportional to cos(Δωt). As noted earlier herein, this reference oscillator is also the oscillator employed in the conventional phase lock mechanism establishing the fixed phase relationship between the frequencies of primary laser **3** and local oscillator laser **45** whose differences in frequency, ΔW, are of a very low order. In accordance with known principles of heterodyning lightwaves having fixed phase relationships, heterodyning these signals can produce a difference beat signal small enough to be in the r.f. signal range, but with the frequency difference sufficiently high to provide the heterodyning with a band pass allowing transforming a given binary code rate into corresponding code components of the beat signal, such as the code rate of the PRN code sequence produced by PRN code generator **53**. This reference oscillator wave is passed from the reference oscillator **451** via the electrical path **453** to amplifier **455**. The wave is amplified by amplifier **455** and passed to hybrid coupler **459** via electrical path **447**. The hybrid coupler splits the amplified reference oscillator electronic wave into two components one proportional to cos(Δωt) on electrical path **417** (providing the "I", or In-phase reference); and one proportional to sin(Δωt) on electrical path **427** (providing the "Q", or Quadrature-phase reference).

[0171]The In-phase reference on electrical path **417** is multiplied (or frequency mixed) with the signal on electrical path **411** by multiplier **413** to produce the output on electrical path **415**. The signal on electrical path **415** is amplified by amplifier **431** and passed to electronic lowpass filter **435** via electrical path **433**. The lowpass filter **435** removes high frequency components of the multiplication or frequency mixing process and results in an output at electrical path **313** which is proportional to cos(Φ$_{(m)}$).

[0172]The Quadrature-phase reference on electrical path **427** is multiplied (or frequency mixed) with the signal on electrical path **421** by multiplier **423** to produce the output on electrical path **425**. The signal on electrical path **425** is amplified by amplifier **441** and passed to electronic lowpass filter **445** via electrical path **443**. The lowpass filter **445** removes high frequency components of the multiplication or frequency mixing process and results in an output at electrical path **315** which is proportional to sin(Φ$_{(m)}$).

[0173]k. Phase Detector

[0174]Example implementations of the phase detection **317** of FIG. 8 will now be presented. Refer to FIG. 10. An example digital phase detector implementation, **317**, is shown in the block diagram. The signal proportional to cos(Φ$_{(m)}$) on electrical path **313** is converted to a digital code or number by analog-to-digital converter (hereafter, A/D) **513**. The digital number proportional to cos (Φ$_{(m)}$) is input into the digital signal processor **501** via electrical path **515**. The signal proportional to sin (Φ$_{(m)}$) on electrical path **315** is converted to a digital code or number by A/D **523**. The digital number proportional to sin(Φ$_{(m)}$) is input into the digital signal processor, **501**, via electrical path **525**. The digital signal processor converts the numbers proportional to sin (Φ$_{(m)}$) and cos (Φ$_{(m)}$) into a number proportional to Φ$_{(m\ )}$as follows.

[0175]Suppose the constant of proportionality for the sin(Φ$_{(m)}$) and cos (Φ$_{(m)}$) is V$_{(m)}$. Then the digital signal processor can optimally select estimates of Φ$_{(m\ )}$and V$_{(m\ )}$to minimize the calculated error function: ϵ([circumflex over (Φ)]$_{(m)}$,*[circumflex over (V)]*$_{(m)}$)=((*V*$_{(m\ )}$cos(Φ$_{(m)}$)−*[circumflex over (V)]*$_{(m\ )}$cos([circumflex over (Φ)]$_{(m)}$))$^{(2)}$+(*V*$_{(m\ )}$sin(Φ$_{(m)}$)−*[circumflex over (V)]*$_{(m\ )}$sin(Φ$_{(m)}$))$^{(2)}$) (42)

[0176]The digital signal processor can also calculate Φ$_{(m\ )}$directly by taking the inverse tangent function or the inverse cotangent function:

[0177]Φm=a⁢⁢tan⁡(Vm⁢sin⁡(Φm)Vm⁢cos⁡(Φm))=a⁢⁢cot⁡(Vm⁢cos⁡(Φm)Vm⁢sin⁡(Φm))(43)

[0178]If desired, the digital signal processor can also implement the differentiate and cross multiply (hereafter DCM) algorithm. The DCM method is as follows. The digital representation of the signals proportional to sin (Φ$_{(m)}$) and cos(Φ$_{(m)}$) are temporally differentiated and cross multiplied by the non-differentiated signals. The result U$_{(m)}$(t) is integrated to produce the desired output, Φ$_{(m)}$. Mathematically, this algorithm is:

[0179]Um⁡(t)=⁢Vm⁢sin⁡(Φm)⁢∂∂t⁢(Vm⁢cos⁡(Φm))-⁢Vm⁢cos⁡(Φm)⁢∂∂t⁢(Vm⁢sin⁡(Φm))Um⁡(t)=⁢Vm2⁡((cos⁡(Φm))2+(sin⁡(Φm))2)⁢∂Φm∂tUm⁡(t)=⁢Vm2⁢∂Φm∂tΦm=⁢1Vm2⁢?Um⁡(t)⁢∂t.(44) The digital signal processor **501** converts the signals arriving on electrical paths **515** and **525** into a digital output proportional to Φ$_{(m\ )}$on electronic path **503**. Optionally, the digital output is passed on electronic path **505** to some other data sink such as a computer memory. The digital signal proportional to

Φ$_{(m)}$on electronic path **503** is converted back to an analog signal on electrical path **319** by digital-to-analog converter **507**. By way of a summarization, the example digital phase detector **317** accepts inputs **313** and **315** which originate from the I & Q demodulator, **311**, of FIG. 8, and the digital phase detector **317** outputs the phase signal Φ$_{(m)}$on electrical path **319**. Optionally, any of other well-known implementations of digital phase detectors may be employed.

[0180]Refer to FIG. 11. An example analog phase detector implementation, **317**′ is shown in the block diagram. The example analog phase detector **317**′ shown in FIG. 11 implements an analog version of the DCM algorithm discussed in the previous text. The signal proportional to cos (Φ$_{(m)}$) on electrical path **313** is input into analog temporal differentiator **613** and analog multiplier **617**. The signal proportional to sin(Φ$_{(m)}$) on electrical path **315** is input into analog temporal differentiator **623** and analog multiplier **627**. The differentiated cosine term on signal path **625** is multiplied by the sine term on electrical path **315** by analog multiplier **627** producing the signal on electrical path **629**. The differentiated sine term on electrical path **615** is multiplied by the cosine term on electrical path **313** by analog multiplier **617** producing the signal on electrical path **619**. The signals on electrical paths **619** and **629** are applied as inputs to differential summer **631**. The output of differential summer on electrical path **633**, which is the result of the differentiated sine and cosine product being subtracted from the differentiated cosine and sine product, corresponds to $U_{(m)}(t)$ of the DCM discussion. The signal on electrical path **633** is integrated by analog integrator **635** to produce the analog phase detector output proportional to Φ$_{(m)}$on electrical path and output **319**. By way of summarization, the example analog phase detector **317** accepts inputs **313** and **315** which originate from the I & Q demodulator **311** of FIG. 8, then the analog phase detector outputs the phase signal Φ$_{(m)}$on electrical path **319**. Optionally, any of other well-known implementations of analog phase detectors may be employed.

[0181]1. Programmable Phase Difference

[0182]The example programmable phase differencer implementation shown as part **99** of FIG. 12 corresponds to part **99** shown as a block in FIG. 3. Refer to FIG. 12. The plurality (which upwardly may include a very large number, for instance 5,000) of demodulated signals proportional to optical signal phases Φ$_{(1)}$, Φ$_{(2)}$, . . . Φ$_{(n)}$are input into the programmable phase signal switching and routing network **701** via electrical paths **71**, **73** and **75**, respectively. Network **701** programmably selects on a basis of timed relation to code generator **53** and routes on a basis of conventional "hold-in memory" and "transfer-from-memory", a plurality (which upwardly may include a very large number, for instance 5,000) of pairs of phase signals onto a plurality (which upwardly may include a very large number, for instance 5,000) of pairs of electronic paths **711** and **713**, **731** and **733** and **751** and **753**. The plurality of routed pairs of phase signals are applied to the corresponding of subtracters **715**, **735** and **755** as shown on FIG. 12. The plurality of phase pairs on electronic pairs of paths **711** and **713**, **731** and **733**, and **751** and **753** are subtracted by subtracters **715**, **735** and **753**, respectively, and the differential signal are outputted on a corresponding plurality of electrical paths **91**, **93** and **95** respectively. The following description focuses on the differencing channel output on electrical path **91**, it being understood that the modes of operation of other differencing channels in network **701** are the same. Programmable phase switching and routing network **701** selects one of the phase signals on one of the plurality of electrical paths **71**, **73** or **75** and routes the signal to electrical path **711**. The signal on electrical path **711** is selected to be proportional to Φ$_{(j)}$(where j is of the set 1,2 . . . n). Network **701** also selects another of the phase signals on one of the other of the plurality of electronic paths **71**, **73** or **75** and routes the signal to electrical path **713**. The signal of electrical path **713** is selected to be proportional to Φ$_{(k)}$(where k is of set 1,2 . . . n). The signal on electrical path **711** is subtracted from the signal on electrical path **713** by subtracter **715**. The output of subtracter **715** is passed on via electrical path **91** and is proportional to ΔΦ$_{(kj)}$hereinabove discussed in subsection 3(f) "Phase Differencing" of this DESCRIPTION OF THE PREFERRED EMBODIMENT. Employing this mode, network **701** programmably makes selection from optical signal phases Φ$_{(1)}$, Φ$_{(2)}$, . . . Φ$_{(n)}$to provide other differential phase outputs on electrical paths **91**, **93** and **95**. This may include a very large number of differential phase signals, for instance 5000. As an alternative to the just described type of circuitry employing subtracters **715**, **735** and **755** any of other well-known forms of producing a differential signal my be employed.

[0183]m. An Alternative Viewpoint of the Partitioning of System **2**.

[0184]As an alternative to the viewpoint inferable from the preceding sequence discussing FIG. 3, system **2** may be considered as partitioned into: (i) an optical network for illuminating an optical fiber sensing span, or other light propagation medium sensing span, and retrieving back propagating portions of the illumination; and (ii) a photoelectronic network for establishing virtual sensors at predetermined locations along the span and picking up external physical signals incident to, or impinging upon, the sensors.

[0185]In general, the optical network for the illumination of, and for the retrieval of back-propagation from, fiber span **9** comprises transmitter laser **3**, directional optical coupler **7**, and optical fiber, or other light propagation medium **9**.

[0186]The photoelectronic network for establishing virtual sensors and picking up signals therefrom generally comprises two subdivisions. One subdivision provides a cyclically reiterative autocorrelatable form of modulation of the lightwave illuminating fiber span **9**. This modulation is in the form reiterated sequences having autocorrelatable properties. The other subdivision takes the retrieved back propagation and performs a heterodyning therewith to obtain an r.f. beat signal. It then picks up the signal from the virtual sensors by autocorrelation and further processes it into more useful forms.

[0187]In general, the subdivision providing the cyclical reiterative modulation of sequences illuminating fiber span **9** comprises master correlation code generator **53** (via one of its electrical pathway outputs) and optical modulator **5**.

[0188]In general, the subdivision for performing heterodyning with and picking up of virtual sensor signals from the retrieved back propagation from fiber span **9** includes local oscillator laser **45**, and the network which phase locks transmitter laser **3** and local oscillator **45**, and a sequence of elements which perform processing upon the retrieved back propagation. The phase locking network comprises beamsplitter **4**, phase locking means optical receiver **35**, phase locking circuitry **30**, and optical coupler **43**. First in the sequence of processing elements is an optical receiver **15** which photodetects interference power "derived" by heterodyning the back propagated illumination portion retrieved from fiber span **9** with the output of a local oscillator **45**. Lasers **3** and **45** are operated with a frequency difference to produce an r.f. beat signal, ΔW. Then correlation system **23** receives as one of its inputs another electrical pathway output from master correlation code generator **53**, and provides a series of channels which in turn respectively provide predetermined time delays in relation to the timing base of cyclic reiterative code generator **53**, to perform a series of autocorrelations of the respectively delayed inputs from code generator **53** with the signal ΔW. This picks up r.f. signals respectively representative of the affects in the lightwave domain of the external physical signals incident upon the respective virtual sensor. Phase demodulator system **66** provides a linear phase signal derived from such r.f. signals representative of optical signals at the respective virtual sensors. Programmable phase differencer **99** processes pairs of these linear phase signals occurring across segments of fiber span **9** between programmably selected pairs of the virtual sensors.

[0189]Following is another overview description which more particularly calls attentions to an aspect of the invention that the system elements which performs the autocorrelation enable providing an output in the form of an r.f. counterpart of a lightwave time-domain reflectometry output of signals incident to the virtual sensors as lightwave time domain reflectometry outputs a CW lightwave modulated by a continuously reiterated binary pseudorandom code sequence is launched into an end of a span of ordinary optical fiber cable. Portions of the launched lightwave back propagate to the launch end from a continuum of locations along the span because of innate fiber properties including Rayleigh scattering. This is picked off the launch end and heterodyned to produce an r.f. beat signal. The r.f. beat signal is processed by a plurality (which can be thousands) of correlator type binary pseudonoise code sequence demodulators respectively operated in different delay time relationships to the timing base of the reiterated modulation sequences. The outputs of the demodulators provide r.f. time-domain reflectometry outputs representative of signals (e.g., acoustic pressure waves) incident to virtual sensors along the fiber at positions corresponding to the various time delay relationships.

[0190]Following is still another overview description which more particularly calls attention to an aspect of the invention that the system elements performing the autocorrelation enable detection of unique spectral components representing a phase variations of external signals incident to the virtual sensors. A CW lightwave modulated by a continuously reiterated pseudorandom code sequence is launched into an end of a span of ordinary optical fiber cable. Portions of the launched lightwave back propagate to the launch end from a continuum of locations along the span because of innate fiber properties including Rayleigh scattering. This is picked off the launch end and heterodyned producing an r.f. beat signal. The r.f. beat signal is processed by a plurality (which can be thousands) of correlator type pseudonoise code sequence demodulation and phase demodulator units, operated in different time delay relationships to the timing base of the reiterated modulation sequences. These units provide outputs representative of phase variations in respective unique spectral components in the r.f. beat signal caused by acoustic, or other forms of signals, incident to virtual sensors at fiber positions corresponding to the various time delay relationships.

[0191]Following is yet another overview description which more particularly calls attention to an aspect of the invention that a pair of the different delay time relationships of the autocorrelation system elements are effective to establish a virtual increment of the optical fiber span, and that a substracter circuit of phase differencer **99** enables representing the differential phase signal across the virtual increment. A CW lightwave modulated by a continuously reiterated pseudorandom (PN) code sequence is launched into an end of a span of ordinary optical fiber cable. Portions of the launched lightwave back propagate to the launch end from a continuum of locations along the span because of innate fiber properties including Rayleigh scattering. This is picked off the launch end and heterodyned producing an r.f. beat signal. The r.f. beat signal is processed by a plurality (which can be thousands) of correlator pseudonoise code sequence demodulation and phase demodulator units operated in different delay time relationships to the timing base of the reiterated modulation sequences. Pairs of outputs of the units are connected to respective substracter circuits, each providing a signal representative of phase differential of incident acoustic signals, or other forms of signals, across virtual increments of the span established by a pair of said delay time relationships.

[0192]n. Air-Backed Mandrel Modified Form of Invention

[0193]FIG. 13 illustrates a so-called fiber-on-an-air-backed mandrel assembly **801**, useful in applications in which a fiber optic span **9**′ is to be immersed in a liquid medium. Assembly **801** comprises a hollow cylindrical mandrel **803** having formed therein a sealed central chamber **805** containing air or other gaseous medium **807**, which is compressible relative to the liquid medium. A segment of span **9**′ of a ROSE system **2**, FIG. 3, is helically wound the cylindrical exterior surface of mandrel **803**, and suitably fixedly bonded to the surface. The cylindral wall **809** of mandrel **803** is of a material so chosen and of a thickness so chosen to form a containic membrane with a hoop stiffness that enables acoustic pressure wave signals incident upon assembly **801** to be transformed into mandrel radial dimensional variations. As a result of mandrel **801**'s geometry these radial variations result in magnified longitudinal strain variations in fiber **9**′. It is to be appreciated that the physical structure of assembly **801** inherently provides a spatial succession of two locations along the fiber span, which a phase signal switch and routing network **701** could select and route to become the virtual bounding positions of a differential phase signal virtual sensor. This is to say, positioning a mandrel wound span **9**′ as a segment of a system total span **9** of ROSE system **2** can facilitate providing a sequential pair of virtual sensor locations along a span **9**, and the provision of a corresponding pair of delay circuits in correlator circuit **23** would cause assembly **801** to operate as a differential phase signal sensor.

(4) Advantages and New Features

[0194]The invention enables the interrogation or time-delay correlational multiplexing and demultiplexing of optical phase signals.

[0195]The invention enables the interrogation of ROSE (Rayleigh Optical Scattering and Encoding) fiber optic sensors. The invention enables the spatial sorting and separation of the temporal optical phases of backscattered optical signals arising from a plurality (which upwardly may include a very large number, for instance 5,000) of virtual optical sensors along fibers or other optical mediums. The invention enables the spatial decoding of backscattered optical signals with a bandwidth of tens of kilohertz. The invention enables the sensor locations along the fiber to be programmable. The invention allows the electronic separation or segmentation of the array of fiber sensors into programmable bounded lengths and positions. Because the correlation signal, c(t), can be designed to be a continuous wave, the invention increases the average optical power considerably over conventional pulsed optical phase sensor interrogation methods. Because the correlation signal c(t) can be chosen to have spectrum spreading properties for which dispreading electronic circuitry is readily available, undesired optical fiber system noises, such as reflection discontinuity noises due to cable couplings, can be materially attenuated.

[0196]In hypothetically assessing the potential achievable by the present invention with regard to employment of a common grade of optical fiber cable buried beneath the ground surface as a perimeter intrusion monitoring fiber span, the following assumptions have been made: (i) signal to noise ratio (S/N) degradation of Rayleigh effect light propagation in such an optical fiber cable are assumed to be 0.5 db/km; (ii) it is assumed there is a requirement for bandwidth of ten times that of the geo-acoustic intruder signal needs to be detected; (iii) and digital circuitry functions are performed employing conventional "high end" clock rates. Using these assumptions, and employing conventional single-mode or multimode fiber buried 6-12 inches underground, and using conventional engineering methodology for noise effect prediction, it can be shown that ROSE system **2** has the potential of sensing intruder caused geo-acoustic, (i.e., seismic) signals along a length of fiber span line as long as 8 km or 5 miles. (This assessment is based upon S/N degradations for flyback travel of signals from the interrogation launch end of fiber span **9** to its remote end and back.) The hypothetical segment resolution capability with such a 8 km., or 5 mile line, would be 1 meter.

[0197]The invention provides a new capability of heterodyne optical phase detection without resorting to dithered phase carrier methods. The phase demodulation method introduces heterodyne I & Q demodulation to produce cosine and sine phase components, clipped signal amplitude stabilization techniques and digital signal processing based phase detection. The spatially differential phase detection method provided by the invention enables the rejection of unwanted lead-in fiber phase signals.

[0198]The details, materials step of operation and arrangement of parts herein have been described and illustrated in order to explain the nature of the invention. Many modifications in these are possible by those skilled in the art within the teachings herein of the invention. For example, while in system **2** the transformation from optical to r.f. signal takes place prior to processing by programmable correlation **23**, it is within the skill of the art to design optical receiver **15** and correlator system **23** to have the transformation take place otherwise. Also, as an alternative to the previously described mechanism for phase locking laser **3** and **45**, the laser optical wave on an optical path **39** can be passed through an acoustic-optic modulator, sometimes called a Bragg Cell. The diffracted optical wave exiting the acousto-optic modulator will be Doppler shifted by an impinging-driving RF wave, that is translated into a sound wave in the acousto-optic modulator, and the so-called Bragg shifted-diffracted optical wave will exit the acousti-optical modudulator with an optical frequency equivalent to the phase locked laser **45**. The acousto-optically generated lightwave, at an equivalent frequency of the phase locked laser **45**, is sent along optical pathway **13** and becomes the local oscillator input to heterodyne photoreceiver **15**. An acousto-optically frequency shifted version of the light in optical path **39** can therefore replace the phase locked light of coherent optical source **45**. Accordingly it is to be understood that changes may be made by those skilled in the art within the principle and scope of the inventions expressed in the appended claims.

ENGLISH-CLAIMS:
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What is claimed is:

1. A time-domain reflectometer for sensing at a desired set of n spaced sensing positions along an optical fiber span, said sensing positions being for sensing a type of external physical signal having the property of inducing light path changes within the optical fiber span at regions there along where the signal is coupled to the span, comprising:

- -

  an optical fiber span having a first end which concurrently serves as both the interrogation signal input end and the back propagating signal output end for purposes of reflectometry, and having a second remote end;
- -

  a first light source for producing a coherent carrier lightwave signal of a first predetermined wavelength;
- -

  a binary pseudonoise code sequence modulator modulating said carrier signal for producing a pseudonoise code sequence modulated interrogation lightwave signal which continuously reiterates the binary pseudonoise code sequence, the reiterated sequences being executed in a fixed relationship to a predetermined timing base;
- -

  a lightwave heterodyner having first and second inputs for receiving a primary signal and a local oscillator signal, respectively, and operative to produce the beat frequencies of their respective frequencies;
- -

  a lightwave directional coupler having a first port which receives said binary pseudonoise code sequence modulated interrogation lightwave, a second port coupled to said first end of said optical fiber span, and a third port coupled to said primary signal input of the heterodyner;
- -

  said directional coupler coupling said binary pseudonoise code sequence modulated interrogation lightwave to said second port where it is launched in a forwardly propagating direction along said optical fiber span causing the return to said second port of a composite back-propagating lightwave which is a summation of lightwave back-propagations from a continuum of locations along the length of the span, said composite back-propagating lightwave signal comprising a summation of multiple components including

- -

  a first signal component comprising the summation of portions of the said pseudonoise code sequence modulated interrogation lightwave signal which the innate properties of the optical fiber cause to backpropagate at a continuum of locations along the span, and
- -

  a second signal component comprising the modulation of said first signal component caused by longitudinal components of optical path changes induced into said span at a continuum of locations along said span by external physical signals, said second signal component further including a corresponding set of subcomponents comprising the modulation of said first signal component by optical path changes caused by said external signals at the respective sensing positions;

- -

  said directional coupler coupling said composite back-propagating lightwave to said third port where it is applied to said first input of the heterodyner;
- -

  a second light source coupled to said second input of the lightwave heterodyner, said second light source producing a coherent local oscillator lightwave signal in phase locked relation to said carrier lightwave signal, said local oscillator signal being of a second predetermined wavelength which differs from the first predetermined wavelength by an amount of difference small enough to produce at the output of the heterodyner a radio frequency (r.f.) composite difference beat signal, but by an amount large enough to cause said r.f. composite difference beat signal to have sufficient bandwidth to cause it to include r.f. counterparts of signal components and subcomponents of said composite back propagating lightwave signal;
- -

  said r.f. composite difference beat frequency signal being coupled to an n-way splitter providing a corresponding set of n output channels, each transmitting said r.f. composite difference beat signal;
- -

  a corresponding set of n correlation-type binary pseudonoise code sequence demodulators having their respective inputs connected to the corresponding output channels of said n-way splitter through a corresponding set of time delay circuits which respectively provide a corresponding set of predetermined time delays in relation to said predetermined timing base of the binary pseudonoise code sequence modulator, to establish said n desired sensing positions along said optical fiber span; and
- -

  said set of correlation-type binary pseudonoise code sequence demodulators serving to conjunctively temporally and spatially de-multiplex said r.f. composite difference beat signal to provide at their respective outputs r.f. counterparts of the subcomponents of said second signal component of said composite back-propagating lightwave signal caused by changes in the optical path within said optical fiber span induced by external physical signals respectively coupled to the corresponding sensing positions.

2. The reflectometer of claim 1 wherein:

- -

  said innate properties of the said optical fiber material include the generation of Rayleigh optical scattering effects at a continuum of locations along said optical fiber span in response to said forwardly propagating binary pseudonoise code sequence modulated interrogation lightwave.

3. The reflectometer of claim 1 wherein said type of external physical signal which induces light path changes in said optical fiber span is an acoustic pressure wave signal.

4. The reflectometer of claim 3, wherein:

- ~

  said optical fiber span is an acoustic security alarm perimeter monitoring line buried at a predetermined depth beneath the surface of the ground;
- ~

  said acoustic pressure wave signal being caused by the vibration of the ground surface by movement of an object thereon; and
- ~

  said set of n sensing positions along the line form a virtual array of n geophones which respectively produce substantially linear signals respectively representative of the vibrations of the surface of the ground at corresponding sensing positions.

5. The reflectometer of claim 4 wherein the range of depths of burial of the optical fiber span beneath the surface of the ground is of six inches to the order of one foot.

6. The reflectometer of claim 3 wherein:

- ~

  said optical fiber span is of a length L; and
- ~

  said first light source is a laser having the performance capability to generate a lightwave signal with sufficient phase stability to substantially retain coherency in propagation along said optical fiber span for a distance at least equal to 2 L.

7. The reflectometer of claim 6, wherein:

- ~

  said the length L of said optical fiber span is at least 5.0 km.

8. The reflectometer of claim 7 wherein said first light source is a planar, ring-type laser.

9. The reflectometer of claim 3 wherein said optical fiber span comprises a single-mode fiber optic cable.

10. The reflectometer of claim 3 wherein said optical fiber span comprises a fiber optic cable of the polarization preserving type.

11. The reflectometer of claim 3, wherein:

- ~

  said optical fiber span has a coating made of a thermoplastic material having the combined characteristics of a low Young's modulus and a Poisson's ratio below that of natural rubber; and
- ~

  said coating serving to enhance the longitudinal component of strain variation derived from an acoustic wave signal whose wave front is incident to the span from a direction at least in part having a lateral component in the direction along which the wave front propagates.

12. The reflectometer of claim 1 wherein:

- said lightwave heterodyner is of the photodetector type.

13. The reflectometer of claim 12 wherein:

- said lightwave heterodyner of the photodetector type is a balanced optical detector circuit including a matched pair of photodetectors with the composite back-propagating lightwave signal applied to each photodetector of the pair; and
- said balanced optical detection circuit produces said r.f. composite difference beat signal as a differential current from the matched pair of photodetectors.

14. The reflectometer of claim 1 wherein the continuously reiterated binary pseudonoise code sequences are binary pseudonoise sequences wherein shifts between binary states of the signal alternatingly shift the radian phase of the carrier between substantially 0° and substantially 180°.

15. The reflectometer of claim 1 wherein said pseudonoise code sequence is a pseudorandom number (PN) code sequence generated by a shift-register type PRN code generator.

16. The reflectometer of claim 1, and:

- a fixed frequency reference oscillator which produces a reference phase signal;
- each phase demodulator including an I & Q quadrature demodulator having a first input for receiving said reference phase signal and a second input for receiving an r.f. counterpart of the corresponding subcomponent of said second signal component of said composite back-propagating lightwave signal, said I & Q demodulator being operative to derive from said reference phase signal an interim in phase signal and an interim quadrature phase signal and to split the signal received at its second input and mix one part thereof with the interim in phase signal and another part thereof with the interim quadrature phase signal to provide a pair of output signals; and
- each phase demodulator further including a phase detector having a pair of inputs for receiving respectively one and the other of said outputs of the I & Q demodulator and operative to provide at the output of the phase demodulator said signal representative of the radian phase of the respective subcomponent of said set of n subcomponents.

17. The reflectometer of claim 16, wherein said reference phase signal produced by said fixed frequency oscillator is used in establishing the phase locked relationship between the local oscillator lightwave signal and the carrier lightwave signal.

18. The reflectometer of claim 1, wherein:

- -

  a time period TP is required for forward propagation of said autocorrelatable spectrum spreading signal from the output of the source of the spectrum spreading signal to where said first light source is modulated, and then for the forward propagation of the derivative spread spectrum modulated interrogation lightwave signal to the second remote end of the fiber optical span, plus the time period required for the back propagation of a subcomponent of said composite back-propagating CW lightwave signal produced at the remote end of the span to the input of the heterodyner, and then for the back propagation of the derivative counterpart subcomponent of the r.f. composite difference beat signal from the output of the heterdyner to the input of a corresponding de-spreader and de-multiplexer of said set of n de-spreader and de-multiplexers; and
- -

  the temporal length of a single autocorrelatable spectrum spreading signal sequence of the continuously reiterated code sequences is one of one and the other of
  - -

    less than the time period TP, and
  - -

    greater than the time period TP.

19. The reflectometer of claim 1, wherein said type of external physical signal which induces light path changes in said optical fiber span is a selected one of a group consisting of: (i) a seismic signal wherein with the media which couples the signal to said optical fiber span includes at least in part the ground in which the fiber optic span is buried; (ii) an underwater sound signal wherein the media which couples the signal to said optical fiber span includes at least in part a body of water in which the fiber optic span is immersed; (iii) an electromagnetic force field coupled to the optical fiber span; (iv) a signal comprising temperature variations coupled to the optical fiber span; and (v) at least one microphonic signal which is coupled to said optical fiber span at an at least one of said set of n sensing positions along the optical fiber span.

20. The reflectometer of claim 1, wherein each of: (i) said coherent carrier lightwave signal; (ii) said coherent local oscillator lightwave signal; (iii) said spread spectrum modulated interrogation lightwave signal; (iv) said composite back-propagating lightwave signal; (v) said radio frequency (r.f.) composite difference beat signal; and (vi) each counterpart of said r.f. counterpart of the subcomponents of said second signal component of said composite back-propagating lightwave signal, is a continuous wave (CW) signal.

21. A system wherein, at respective sensing stations of a plurality of sensing stations along a span of optical fiber, the system senses input signals of a type having a property of inducing light path changes at regions of the span influenced by such input signals, comprising:

- -

  means for illuminating an optical fiber span with a CW optical signal;
- -

  means for retrieving back-propagating portions of the illumination back propagating from a continuum of locations along the span;
- -

  means for modulating said CW optical signal with a reiterative autocorrelatable form of modulation;
- -

  means for picking off a radio frequency (r.f.) counterpart of the retrieved signal, wherein the r.f. counterpart is in phase locked synchronism with the CW optical signal;
- -

means for performing a corresponding plurality of autocorrelation detections upon said (r.f.) counterpart of the retrieved optical signal wherein said performing of the respective autocorrelation detections of the plurality of autocorrelation detection by said means for performing autocorrelation-detections are done in a corresponding plurality of different timed relationships with respect to the reiterative autocorrelatable form of modulation of the CW optical signal.

22. Signal sensing apparatus for sensing input signals at an array of a plurality of sensing stations along an optical fiber span, wherein at respective sensing station of the array the apparatus senses input signals of a type having the property of inducing light path changes within regions influenced by such input signals, said apparatus comprising:

- ~

  an optical wave network comprising a transmitter laser and a lightwave directional coupler, said network being operative to illuminate an optical fiber span with a CW optical signal and to retrieve portions of the illumination back-propagating from a continuum of locations along the fiber span;
- ~

  a modulator operative to modulate the CW optical signal in accordance with a reiterative autocorrelatable form of modulation code;
- ~

  a heterodyner which, in phase locked synchronism with said transmitter laser, receives said retrieved back-propagated portions of illumination and derives therefrom a radio frequency (r.f.) counterpart; and
- ~

  a corresponding plurality of autocorrelation detectors operative upon said r.f. counterpart of the retrieved optical signal in respective timed relationships of a corresponding plurality of different timed relationsips with respect to said reiterative autocorrelatable form of modulation code.

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Natural fiber span reflectometer providing a virtual signal sensing array capability

Payton, Robert Michael (Inventor). US HEALTH (Assignee). **US 7030971** B1. (Published 18 Apr 2006).

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Citation/Abstract

Natural fiber span reflectometer providing a virtual signal sensing array capability

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EP 1779090 A2	04 Mar 2015	EP INTG +	ANNOUNCEMENT OF INTENTION TO GRANT	Effective: 2015 Feb 04 Created: 2015 Mar 04
EP 1779090 A2	30 Oct 2013	EP RIC1	CLASSIFICATION (CORRECTION)	IPC change: G01L 11/02 20060101AFI20130926BHEP Created: 2013 Oct 30
EP 1779090 A2	30 Oct 2013	EP RIC1	CLASSIFICATION (CORRECTION)	IPC change: G01L 1/24 20060101ALI20130926BHEP Created: 2013 Oct 30
				IPC change: G01M 11/00

EP 1779090 A2	30 Oct 2013	EP RIC1	CLASSIFICATION (CORRECTION)	20060101ALI20130926BHEP Created: 2013 Oct 30
EP 1779090 A2	26 Sep 2013	EP REG/DE R079	REFERENCE TO A NATIONAL CODE: AMENDMENT OF IPC MAIN CLASS	Related publication: DE 602005047047 Ref country: DE PREVIOUS MAIN CLASS: G01N0021000000 IPC change: G01L0011020000 Created: 2015 Jul 25
EP 1779090 A2	29 May 2013	EP 17Q +	FIRST EXAMINATION REPORT	Effective: 2013 Apr 29 Created: 2013 May 30
EP 1779090 A2	09 Mar 2011	EP A4 +	SUPPLEMENTARY SEARCH REPORT	Effective: 2011 Feb 07 Last revised: 2011 Mar 10
EP 1779090 A2	02 Mar 2011	EP RIC1	CLASSIFICATION (CORRECTION)	IPC change: G01L 1/24 20060101AFI20070531BHEP Last revised: 2011 Mar 03
EP 1779090 A2	02 Mar 2011	EP RIC1	CLASSIFICATION (CORRECTION)	IPC change: G01M 11/00 20060101ALI20110126BHEP Last revised: 2011 Mar 03
EP 1779090 A2	02 Mar 2011	EP RIC1	CLASSIFICATION (CORRECTION)	IPC change: G01B 9/02 20060101ALI20110126BHEP Last revised: 2011 Mar 03
EP 1779090 A2	14 Nov 2007	EP DAX -	REQUEST FOR EXTENSION OF THE EUROPEAN PATENT (TO ANY COUNTRY) DELETED	Last revised: 2007 Nov 15
EP 1779090 A2	04 Jul 2007	EP RIC1	CLASSIFICATION (CORRECTION)	IPC change: G01B 9/02 20060101ALI20070531BHEP Last revised: 2007 Jul 05
EP 1779090 A2	04 Jul 2007	EP RIC1	CLASSIFICATION (CORRECTION)	IPC change: G01L 1/24 20060101AFI20070531BHEP Last revised: 2007 Jul 05
EP 1779090 A2	02 May 2007		Date of publication of unexamined document not granted on or before said date	
EP 1779090 A2	02 May 2007	EP 17P +	REQUEST FOR EXAMINATION FILED	Effective: 2007 Feb 12 Last revised: 2007 May 03
				Designated states: AT BE BG

EP 1779090 A2	02 May 2007	EP AK +	DESIGNATED CONTRACTING STATES:	CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI SK TR Last revised: 2007 May 03
EP 1779090 A4	09 Mar 2011		Date of separate publication of supplementary search report	
WO 2006017702 A3	02 May 2007	WO WWP +	WIPO INFORMATION: PUBLISHED IN NATIONAL OFFICE	Related publication: EP 2005782661 Last revised: 2008 Aug 21
WO 2006017702 A3	12 Feb 2007	WO WWE +	WIPO INFORMATION: ENTRY INTO NATIONAL PHASE	Related publication: EP 2005782661 Last revised: 2008 Aug 21
WO 2006017702 A3	07 Feb 2007	WO NENP	NON-ENTRY INTO THE NATIONAL PHASE IN:	Ref country: DE Last revised: 2007 May 24
WO 2006017702 A3	27 Sep 2006	WO 121	EP: THE EPO HAS BEEN INFORMED BY WIPO THAT EP WAS DESIGNATED IN THIS APPLICATION	Last revised: 2006 Sep 28
WO 2006017702 A3	06 Apr 2006		Date of separate publication of supplementary search report	
WO 2006017702 A3	06 Apr 2006		With international search report	
WO 2006017702 A3	06 Apr 2006		Before the expiration of the term limit for amending the claims and to be republished in the event of the receipt of amendments	
WO 2006017702 A3	16 Feb 2006	WO AL +	DESIGNATED COUNTRIES FOR REGIONAL PATENTS	Designated states: GM KE LS MW MZ NA SD SL SZ TZ UG ZM ZW AM AZ BY KG KZ MD RU TJ TM AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LT LU LV MC NL PL PT RO SE SI SK TR BF BJ CF CG CI CM GA GN GQ GW ML MR NE SN TD TG Last revised: 2006 Mar 02

WO 2006017702 A3	16 Feb 2006	WO AK +	DESIGNATED STATES	Designated states: AE AG AL AM AT AU AZ BA BB BG BR BW BY BZ CA CH CN CO CR CU CZ DE DK DM DZ EC EE EG ES FI GB GD GE GH GM HR HU ID IL IN IS JP KE KG KM KP KR KZ LC LK LR LS LT LU LV MA MD MG MK MN MW MX MZ NA NG NI NO NZ OM PG PH PL PT RO RU SC SD SE SG SK SL SM SY TJ TM TN TR TT TZ UA UG US UZ VC VN YU ZA ZM ZW Last revised: 2006 Mar 02
US 20060066839 A1	30 Mar 2006		Date of publication of unexamined document not granted on or before said date	
WO 2006017702 A2	16 Feb 2006		Date of publication of unexamined document not granted on or before said date	
WO 2006017702 A2	16 Feb 2006		Without international search report and to be republished upon receipt of that report	
EP 1779090 B1	22 Jul 2015		Date of publication of document granted on or before said date	
EP 2950069 A1	06 Jul 2016	EP RBV +	DESIGNATED CONTRACTING STATES (CORRECTION):	Designated states: AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI SK TR Created: 2016 Jul 06
EP 2950069 A1	06 Jul 2016	EP 17P +	REQUEST FOR EXAMINATION FILED	Effective: 2016 May 30 Created: 2016 Jul 06
EP 2950069 A1	30 Dec 2015	EP RIN1	INVENTOR (CORRECTION)	Inventor: PAYTON, ROBERT M. Created: 2016 Jan 09
EP 2950069 A1	02 Dec 2015		Date of publication of examined document not granted on or before said date	
			DIVISIONAL	Related publication: EP

EP 2950069 A1	02 Dec 2015	EP AC	APPLICATION (ART. 76) OF:	1779090 P Created: 2015 Dec 02
EP 2950069 A1	02 Dec 2015	EP AK +	DESIGNATED CONTRACTING STATES:	Designated states: AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI SK TR Created: 2015 Dec 02

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BIB DATA SHEET

CONFIRMATION NO. 5544

SERIAL NUMBER	FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
14/686,161	06/16/2015 **RULE**	356	3992	300099

APPLICANTS

INVENTORS
Robert M Payton, Tomball, TX;

** **CONTINUING DATA** *************************
This application is a CON of 14/190,478 02/26/2014
which is a REI of 11/056,630 02/07/2005 PAT 7030971
which claims benefit of 60/599,437 08/06/2004

** **FOREIGN APPLICATIONS** *************************

** **IF REQUIRED, FOREIGN FILING LICENSE GRANTED** **
06/24/2015

Foreign Priority claimed ☐ Yes ☑ No 35 USC 119(a-d) conditions met ☐ Yes ☑ No Verified and Acknowledged /STEPHEN J RALIS/ Examiner's Signature	☐ Met after Allowance Initials	STATE OR COUNTRY	SHEETS DRAWINGS	TOTAL CLAIMS	INDEPENDENT CLAIMS
		TX	13	16	2

ADDRESS

NUWCDIVNPT / ADELOS
1176 HOWELL STREET, Code 00L
Bldg. 102T
NEWPORT, RI 02841
UNITED STATES

TITLE

NATURAL SPAN REFLECTOMETRY WITH SENSING ZONE SEGMENTS

FILING FEE RECEIVED	FEES: Authority has been given in Paper	
3180	No.____________ to charge/credit DEPOSIT ACCOUNT No.____________ for following:	☐ All Fees ☐ 1.16 Fees (Filing) ☐ 1.17 Fees (Processing Ext. of time) ☐ 1.18 Fees (Issue) ☐ Other ________________ ☐ Credit

BIB (Rev. 05/07).

Index of Claims	Application/Control No. 14686161	Applicant(s)/Patent Under Reexamination PAYTON, ROBERT M
	Examiner STEPHEN J RALIS	Art Unit 3992

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
=	Allowed	÷	Restricted	I	Interference	O	Objected

☐ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

CLAIM		DATE								
Final	Original	07/29/2016								
	1	-								
	2	-								
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	34	✓								
	35	✓								
	36	✓								

Index of Claims	Application/Control No. 14686161	Applicant(s)/Patent Under Reexamination PAYTON, ROBERT M
	Examiner STEPHEN J RALIS	Art Unit 3992

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
=	Allowed	÷	Restricted	I	Interference	O	Objected

☐ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

CLAIM		DATE								
Final	Original	07/29/2016								
	37	✓								
	38	✓								

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
S1	6	"7030971"	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/06 16:04
S2	613539	auto	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/06 16:42
S3	0	S1 and S2	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/06 16:42
S4	5018169	automatic or automatically	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/06 16:43
S5	1	S1 and S4	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/06 16:43
S6	31384	autocorrelation	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/06 16:45
S7	2	S1 and S6	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/06 16:45
S8	1	("7030971").PN.	USPAT; USOCR	OR	OFF	2016/05/06 16:46
S9	1	S6 and S8	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/06 16:47

S10	298957	counterpart	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/10 10:49
S11	1	("7030971").PN.	USPAT; USOCR	OR	OFF	2016/05/10 10:49
S12	1	S10 and S11	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/10 10:49
S13	3021734	processor	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/10 10:51
S14	1	S11 and S13	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/10 10:52
S15	9	varition near2 frequency	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/10 10:56
S16	85305	variation near2 frequency	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/10 10:56
S17	0	S11 and S16	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/10 10:56
S18	199505	variation with frequency	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/10 11:03
S19	0	S11 and S18	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/10 11:03
S20	9017849	well	US-PGPUB; USPAT; USOCR;	OR	ON	2016/05/10 14:25

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S21	6	"7030971"	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/10 14:25
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S23	4	S20 and S22 and S21	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/10 14:25
S24	1	("7030971").PN.	USPAT; USOCR	OR	OFF	2016/05/10 14:26
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S26	52236	well near2 casing	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/10 14:27
S27	0	S24 and S26	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/10 14:27
S28	1	("8085862").PN.	USPAT; USOCR	OR	OFF	2016/05/12 10:17
S29	18037	oil adj line	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/13 13:39
S30	1	("7030971").PN.	USPAT; USOCR	OR	OFF	2016/05/13 13:39
S31	1	S30 and S29	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/13 13:39
S32	876329	virtual	US-PGPUB; USPAT; USOCR;	OR	ON	2016/05/13 13:42

			EPO; JPO; DERWENT			
S33	1	S30 and S32	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/13 13:43
S34	343724	malfunction	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/13 13:52
S35	1	S30 and S34	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/13 13:52
S36	1900624	threshold	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/13 13:56
S37	1	S30 and S36	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/13 13:56
S38	30365	light with (fiber near2 (cable or optoc$3))	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/13 16:12
S39	7516	light with (fiber adj (cable or optoc$3))	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/13 16:12
S40	1730	light near2 (fiber adj (cable or optoc$3))	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/13 16:12
S41	133	G01B11/162.cpc.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/23 14:49
S42	387	G01L11/025.cpc.	US-PGPUB; USPAT; USOCR;	OR	ON	2016/05/23 14:54

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S43	1	("7030971").PN.	USPAT; USOCR	OR	OFF	2016/05/23 15:25
S44	1	2006-184040.NRAN.	DERWENT	OR	ON	2016/05/23 16:20
S45	5	(("5194847") or ("5686986") or ("6043921") or ("6173091") or ("6285806")).PN.	USPAT; USOCR	OR	OFF	2016/05/23 16:22
S46	528	G01L1/242.cpc.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/24 10:28
S47	89	G01M11/3118.cpc.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/24 11:06
S48	2	(("7274441") or ("7271884")).PN.	USPAT; USOCR	OR	OFF	2016/05/24 11:25
S49	458	G01D5/35383.cpc.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/24 15:52
S50	177	G01M11/3172.cpc.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/24 16:40
S51	247	G08B13/186.cpc.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/24 16:54
S52	1446570	electromagnetic	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/25 13:06
S53	114	(US-20140327915-$ or US-20070039925-$ or US-20100060972-$ or US-20130338475-$ or US-20090022500-$ or US-20110075979-$ or US-20100200743-$ or US-20100175460-$ or US-20100150573-$ or US-20050082465-$ or US-20050077455-$ or US-20050002625-$ or US-20050002608-$ or US-20040257218-$ or US-20040213574-$ or US-20040146255-$ or US-20040129868-$ or US-20030021560-$ or US-20020090182-$ or US-	US-PGPUB; USPAT; DERWENT	OR	ON	2016/05/25 13:06

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S54	33	S52 and S53	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/25 13:06
S55	1	"20060013534"	DERWENT	OR	ON	2016/05/25 13:15
S56	1	2003-879847.NRAN.	DERWENT	OR	ON	2016/05/25

						13:15
S57	1733	light near2 (fiber adj (cable or optoc$3))	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/25 13:34
S58	301	S57 and S52	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/25 13:34
S59	2086025	(thermoplastic near2 (polymer or elastomer)) or polyethylene or polystyrene	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/26 13:32
S60	115	(US-20140327915-$ or US-20070039925-$ or US-20100060972-$ or US-20130338475-$ or US-20090022500-$ or US-20110075979-$ or US-20100200743-$ or US-20100175460-$ or US-20100150573-$ or US-20050082465-$ or US-20050077455-$ or US-20050002625-$ or US-20050002608-$ or US-20040257218-$ or US-20040213574-$ or US-20040146255-$ or US-20040129868-$ or US-20030021560-$ or US-20020090182-$ or US-20010019103-$ or US-20060156822-$ or US-20040165809-$ or US-20130222811-$ or US-20120222770-$ or US-20120222487-$ or US-20100254650-$).did. or (US-20060165344-$ or US-20060153487-$ or US-20060071158-$ or US-20060066839-$ or US-20060013534-$ or US-20060008196-$ or US-20050172721-$ or US-20040135075-$ or US-20040093950-$ or US-20010048071-$ or US-20060257066-$ or US-20050213869-$ or US-20050111793-$ or US-20020028034-$ or US-20060028636-$ or US-20050179889-$ or US-20060028637-$ or US-20050046859-$ or US-20050046860-$ or US-20060018586-$ or US-20050271395-$ or US-20050047706-$ or US-20040136652-$ or US-20030141440-$ or US-20010013934-$ or US-20070171400-$).did. or (US-6243508-$ or US-7706641-$ or US-7189959-$ or US-6188824-$ or US-6169835-$ or US-6002646-$ or US-5862449-$ or US-5861974-$ or US-5485745-$ or US-5323114-$ or US-5061860-$ or US-7060964-$ or US-6626043-$ or US-6630658-$ or US-6597821-$ or US-6278811-$ or US-5845033-$ or US-	US-PGPUB; USPAT; DERWENT	OR	ON	2016/05/26 13:32

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S63	13	S60 and S62	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/26 14:19
S64	570	planar with (ring$5) with laser	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/26 14:29
S65	6	S60 and S64	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/26 14:30
S66	31413	light near2 (fiber adj (cable or optic$3))	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/26 14:30
S67	3	S64 and S66	US-	OR	ON	2016/05/26

			PGPUB; USPAT; USOCR; EPO; JPO; DERWENT			14:30
S68	131	S64 not non	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/26 14:33
S69	439	S64 not S68	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/05/26 14:41
S70	2	("2007005").PN.	USPAT; USOCR	OR	OFF	2016/05/27 13:16
S71	0	("20070053805").PN.	USPAT; USOCR	OR	OFF	2016/05/27 13:16
S72	1	("20070053805").PN.	US-PGPUB; USPAT; USOCR	OR	OFF	2016/05/27 13:16
S73	241265	thermoplastic near2 (polymer or elastomer)	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/01 13:23
S74	31432	light near2 (fiber adj (cable or optic$3))	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/01 13:23
S75	642	S73 and S74	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/01 13:23
S76	3	"20060120675"	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/01 14:02
S77	1	2004-375546.NRAN.	DERWENT	OR	ON	2016/06/01 14:03
S78	4	(polarization adj perserving)	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 14:12
S79	31451	light near2 (fiber adj (cable or optic$3))	US-PGPUB; USPAT;	OR	ON	2016/06/02 14:12

			USOCR; EPO; JPO; DERWENT			
S80	0	S78 same S79	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 14:12
S81	412870	polarization	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 14:13
S82	381	S79 with S81	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 14:13
S83	124	(US-20140327915-$ or US-20070039925-$ or US-20100060972-$ or US-20130338475-$ or US-20090022500-$ or US-20110075979-$ or US-20100200743-$ or US-20100175460-$ or US-20100150573-$ or US-20050082465-$ or US-20050077455-$ or US-20050002625-$ or US-20050002608-$ or US-20040257218-$ or US-20040213574-$ or US-20040146255-$ or US-20040129868-$ or US-20030021560-$ or US-20020090182-$ or US-20010019103-$ or US-20060156822-$ or US-20040165809-$ or US-20130222811-$ or US-20120222770-$ or US-20120222487-$ or US-20100254650-$).did. or (US-20060165344-$ or US-20060153487-$ or US-20060071158-$ or US-20060066839-$ or US-20060013534-$ or US-20060008196-$ or US-20050172721-$ or US-20040135075-$ or US-20040093950-$ or US-20010048071-$ or US-20060257066-$ or US-20050213869-$ or US-20050111793-$ or US-20020028034-$ or US-20060028636-$ or US-20050179889-$ or US-20060028637-$ or US-20050046859-$ or US-20050046860-$ or US-20060018586-$ or US-20050271395-$ or US-20050047706-$ or US-20040136652-$ or US-20030141440-$ or US-20010013934-$ or US-20070171400-$ or US-20070153839-$).did. or (US-20060120675-$).did. or (US-6243508-$ or US-7706641-$ or US-7189959-$ or US-6188824-$ or US-6169835-$ or US-6002646-$ or US-5862449-$ or US-5861974-$ or US-5485745-$ or US-5323114-$ or US-5061860-$ or US-	US-PGPUB; USPAT; EPO; JPO; DERWENT	OR	ON	2016/06/02 14:23

		7060964-$ or US-6626043-$ or US-6630658-$ or US-6597821-$ or US-6278811-$ or US-5845033-$ or US-5844927-$ or US-5767411-$ or US-5517022-$ or US-5218418-$ or US-5194847-$ or US-5010248-$ or US-4920261-$ or US-4904863-$ or US-6285806-$).did. or (US-6173091-$ or US-6043921-$ or US-5686986-$ or US-6816638-$ or US-6545760-$ or US-6057911-$ or US-5880824-$ or US-4983034-$ or US-6388741-$ or US-5506674-$ or US-5353110-$ or US-4968880-$ or US-4743753-$ or US-7274441-$ or US-7271884-$ or US-6778720-$ or US-6122305-$ or US-5892860-$ or US-5818585-$ or US-5815266-$ or US-5804713-$ or US-5754293-$ or US-5698848-$ or US-5696857-$ or US-5680489-$ or US-5513913-$ or US-5140154-$).did. or (US-4889986-$ or US-6122044-$ or US-5159400-$ or US-4826314-$ or US-4794249-$ or US-5627934-$ or US-4572950-$ or US-4905252-$ or US-6982997-$ or US-5452394-$).did. or (WO-2009079730-$).did. or (JP-05315683-$).did. or (US-5194847-$ or WO-9608695-$ or EP-1359394-$ or WO-03093770-$ or US-7251023-$ or US-20060013534-$ or JP-08046574-$ or WO-2004034096-$).did.				
S84	49	S81 and S83	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 14:23
S85	5978	single adj polarization	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 14:41
S86	149	S79 and S85	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 14:42
S87	2	((polarization adj perserving) adj fiber)	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 14:57
S88	953	((polarization adj preserving) adj fiber)	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 15:47

S89	96	S79 and S88	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 15:47
S90	8322	((polarization adj maintaining) near2 fiber)	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 15:52
S91	430	S79 and S90	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 15:53
S92	125	(US-20140327915-$ or US-20070039925-$ or US-20100060972-$ or US-20130338475-$ or US-20090022500-$ or US-20110075979-$ or US-20100200743-$ or US-20100175460-$ or US-20100150573-$ or US-20050082465-$ or US-20050077455-$ or US-20050002625-$ or US-20050002608-$ or US-20040257218-$ or US-20040213574-$ or US-20040146255-$ or US-20040129868-$ or US-20030021560-$ or US-20020090182-$ or US-20010019103-$ or US-20060156822-$ or US-20040165809-$ or US-20130222811-$ or US-20120222770-$ or US-20120222487-$ or US-20100254650-$).did. or (US-20060165344-$ or US-20060153487-$ or US-20060071158-$ or US-20060066839-$ or US-20060013534-$ or US-20060008196-$ or US-20050172721-$ or US-20040135075-$ or US-20040093950-$ or US-20010048071-$ or US-20060257066-$ or US-20050213869-$ or US-20050111793-$ or US-20020028034-$ or US-20060028636-$ or US-20050179889-$ or US-20060028637-$ or US-20050046859-$ or US-20050046860-$ or US-20060018586-$ or US-20050271395-$ or US-20050047706-$ or US-20040136652-$ or US-20030141440-$ or US-20010013934-$ or US-20070171400-$ or US-20070153839-$).did. or (US-20060120675-$).did. or (US-6243508-$ or US-7706641-$ or US-7189959-$ or US-6188824-$ or US-6169835-$ or US-6002646-$ or US-5862449-$ or US-5861974-$ or US-5485745-$ or US-5323114-$ or US-5061860-$ or US-7060964-$ or US-6626043-$ or US-6630658-$ or US-6597821-$ or US-6278811-$ or US-5845033-$ or US-	US-PGPUB; USPAT; EPO; JPO; DERWENT	OR	ON	2016/06/02 18:01

		5844927-$ or US-5767411-$ or US-5517022-$ or US-5218418-$ or US-5194847-$ or US-5010248-$ or US-4920261-$ or US-4904863-$ or US-6285806-$).did. or (US-6173091-$ or US-6043921-$ or US-5686986-$ or US-6816638-$ or US-6545760-$ or US-6057911-$ or US-5880824-$ or US-4983034-$ or US-6388741-$ or US-5506674-$ or US-5353110-$ or US-4968880-$ or US-4743753-$ or US-7274441-$ or US-7271884-$ or US-6778720-$ or US-6122305-$ or US-5892860-$ or US-5818585-$ or US-5815266-$ or US-5804713-$ or US-5754293-$ or US-5698848-$ or US-5696857-$ or US-5680489-$ or US-5513913-$ or US-5140154-$).did. or (US-4889986-$ or US-6122044-$ or US-5159400-$ or US-4826314-$ or US-4794249-$ or US-5627934-$ or US-4572950-$ or US-4905252-$ or US-6982997-$ or US-5452394-$ or US-6246816-$).did. or (WO-2009079730-$).did. or (JP-05315683-$).did. or (US-5194847-$ or WO-9608695-$ or EP-1359394-$ or WO-03093770-$ or US-7251023-$ or US-20060013534-$ or JP-08046574-$ or WO-2004034096-$).did.				
S93	571	planar with (ring$5) with laser	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 18:01
S94	12	S93 and S92	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 18:01
S95	1	1991-238253.NRAN.	DERWENT	OR	ON	2016/06/02 18:25
S96	80414	single adj mode	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 18:37
S97	130	(US-20140327915-$ or US-20070039925-$ or US-20100060972-$ or US-20130338475-$ or US-20090022500-$ or US-20110075979-$ or US-20100200743-$ or US-20100175460-$ or US-20100150573-$ or US-20050082465-$ or US-20050077455-$ or US-20050002625-$ or US-20050002608-$ or US-20040257218-$ or US-20040213574-$ or US-20040146255-$ or US-20040129868-$ or US-20030021560-$	US-PGPUB; USPAT; EPO; JPO; DERWENT	OR	ON	2016/06/02 18:37

		or US-20020090182-$ or US-20010019103-$ or US-20060156822-$ or US-20040165809-$ or US-20130222811-$ or US-20120222770-$ or US-20120222487-$ or US-20100254650-$).did. or (US-20060165344-$ or US-20060153487-$ or US-20060071158-$ or US-20060066839-$ or US-20060013534-$ or US-20060008196-$ or US-20050172721-$ or US-20040135075-$ or US-20040093950-$ or US-20010048071-$ or US-20060257066-$ or US-20050213869-$ or US-20050111793-$ or US-20020028034-$ or US-20060028636-$ or US-20050179889-$ or US-20060028637-$ or US-20050046859-$ or US-20050046860-$ or US-20060018586-$ or US-20050271395-$ or US-20050047706-$ or US-20040136652-$ or US-20030141440-$ or US-20010013934-$ or US-20070171400-$ or US-20070153839-$).did. or (US-20060120675-$).did. or (US-6243508-$ or US-7706641-$ or US-7189959-$ or US-6188824-$ or US-6169835-$ or US-6002646-$ or US-5862449-$ or US-5861974-$ or US-5485745-$ or US-5323114-$ or US-5061860-$ or US-7060964-$ or US-6626043-$ or US-6630658-$ or US-6597821-$ or US-6278811-$ or US-5845033-$ or US-5844927-$ or US-5767411-$ or US-5517022-$ or US-5218418-$ or US-5194847-$ or US-5010248-$ or US-4920261-$ or US-4904863-$ or US-6285806-$).did. or (US-6173091-$ or US-6043921-$ or US-5686986-$ or US-6816638-$ or US-6545760-$ or US-6057911-$ or US-5880824-$ or US-4983034-$ or US-6388741-$ or US-5506674-$ or US-5353110-$ or US-4968880-$ or US-4743753-$ or US-7274441-$ or US-7271884-$ or US-6778720-$ or US-6122305-$ or US-5892860-$ or US-5818585-$ or US-5815266-$ or US-5804713-$ or US-5754293-$ or US-5698848-$ or US-5696857-$ or US-5680489-$ or US-5513913-$ or US-5140154-$).did. or (US-4889986-$ or US-6122044-$ or US-5159400-$ or US-4826314-$ or US-4794249-$ or US-5627934-$ or US-4572950-$ or US-4905252-$ or US-6982997-$ or US-5452394-$ or US-6246816-$ or US-5177764-$ or US-4955034-$).did. or (WO-2009079730-$ or WO-9111042-$).did. or (JP-05315683-$).did. or (US-5194847-$ or WO-9608695-$ or EP-1359394-$ or WO-03093770-$ or US-7251023-$ or US-20060013534-$ or JP-08046574-$ or WO-2004034096-$ or WO-9111042-					

		$ or WO-9110273-$).did.				
S98	53	S96 and S97	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 18:37
S99	2	"20040136652"	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/02 18:50
S100	1	2002-638116.NRAN.	DERWENT	OR	ON	2016/06/02 18:51
S101	1	1991-238253.NRAN.	DERWENT	OR	ON	2016/06/03 13:00
S102	1	1991-238253.NRAN.	DERWENT	OR	ON	2016/06/03 13:05
S103	4520432	frequency	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/03 14:48
S104	1	("7030971").PN.	USPAT; USOCR	OR	OFF	2016/06/03 14:48
S105	1	S103 and S104	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/03 14:48
S106	6336524	processor or computer	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/03 15:02
S107	1	S104 and S105	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/03 15:02
S108	1	S104 and S106	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/03 15:02
S109	1	("6043921").PN.	USPAT; USOCR	OR	OFF	2016/06/03 15:07
S110	0	("variationorextent").PN.	USPAT; USOCR	OR	OFF	2016/06/03 15:59
S111	6651624	variation or extent	US-PGPUB; USPAT; USOCR;	OR	ON	2016/06/03 15:59

			EPO; JPO; DERWENT			
S112	1	S105 and S111	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/03 15:59
S113	1453028	electromagnetic	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/06 16:10
S114	131	(US-20140327915-$ or US-20070039925-$ or US-20100060972-$ or US-20130338475-$ or US-20090022500-$ or US-20110075979-$ or US-20100200743-$ or US-20100175460-$ or US-20100150573-$ or US-20050082465-$ or US-20050077455-$ or US-20050002625-$ or US-20050002608-$ or US-20040257218-$ or US-20040213574-$ or US-20040146255-$ or US-20040129868-$ or US-20030021560-$ or US-20020090182-$ or US-20010019103-$ or US-20060156822-$ or US-20040165809-$ or US-20130222811-$ or US-20120222770-$ or US-20120222487-$ or US-20100254650-$).did. or (US-20060165344-$ or US-20060153487-$ or US-20060071158-$ or US-20060066839-$ or US-20060013534-$ or US-20060008196-$ or US-20050172721-$ or US-20040135075-$ or US-20040093950-$ or US-20010048071-$ or US-20060257066-$ or US-20050213869-$ or US-20050111793-$ or US-20020028034-$ or US-20060028636-$ or US-20050179889-$ or US-20060028637-$ or US-20050046859-$ or US-20050046860-$ or US-20060018586-$ or US-20050271395-$ or US-20050047706-$ or US-20040136652-$ or US-20030141440-$ or US-20010013934-$ or US-20070171400-$ or US-20070153839-$).did. or (US-20060120675-$).did. or (US-6243508-$ or US-7706641-$ or US-7189959-$ or US-6188824-$ or US-6169835-$ or US-6002646-$ or US-5862449-$ or US-5861974-$ or US-5485745-$ or US-5323114-$ or US-5061860-$ or US-7060964-$ or US-6626043-$ or US-6630658-$ or US-6597821-$ or US-6278811-$ or US-5845033-$ or US-5844927-$ or US-5767411-$ or US-5517022-$ or US-5218418-$ or US-5194847-$ or US-5010248-$ or US-4920261-$ or US-4904863-$ or US-	US-PGPUB; USPAT; EPO; JPO; DERWENT	OR	ON	2016/06/06 16:10

		6285806-$).did. or (US-6173091-$ or US-6043921-$ or US-5686986-$ or US-6816638-$ or US-6545760-$ or US-6057911-$ or US-5880824-$ or US-4983034-$ or US-6388741-$ or US-5506674-$ or US-5353110-$ or US-4968880-$ or US-4743753-$ or US-7274441-$ or US-7271884-$ or US-6778720-$ or US-6122305-$ or US-5892860-$ or US-5818585-$ or US-5815266-$ or US-5804713-$ or US-5754293-$ or US-5698848-$ or US-5696857-$ or US-5680489-$ or US-5513913-$ or US-5140154-$).did. or (US-4889986-$ or US-6122044-$ or US-5159400-$ or US-4826314-$ or US-4794249-$ or US-5627934-$ or US-4572950-$ or US-4905252-$ or US-6982997-$ or US-5452394-$ or US-6246816-$ or US-5177764-$ or US-4955034-$).did. or (WO-2009079730-$ or WO-9111042-$).did. or (JP-05315683-$).did. or (US-5194847-$ or WO-9608695-$ or EP-1359394-$ or WO-03093770-$ or US-7251023-$ or US-20060013534-$ or JP-08046574-$ or WO-2004034096-$ or WO-9111042-$ or WO-9110273-$ or GB-2372100-$ or WO-02065181-$ or GB-2372100-$ or US-5177764-$).did.				
S115	37	S113 and S114	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/06 16:11
S116	4	"11056632"	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/13 14:57
S117	12	(Payton near2 (Robert near2 Michael)).in.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/16 13:47
S118	131	(US-20140327915-$ or US-20070039925-$ or US-20100060972-$ or US-20130338475-$ or US-20090022500-$ or US-20110075979-$ or US-20100200743-$ or US-20100175460-$ or US-20100150573-$ or US-20050082465-$ or US-20050077455-$ or US-20050002625-$ or US-20050002608-$ or US-20040257218-$ or US-20040213574-$ or US-20040146255-$ or US-20040129868-$ or US-20030021560-$ or US-20020090182-$ or US-20010019103-$ or US-20060156822-$ or US-20040165809-$ or US-	US-PGPUB; USPAT; EPO; JPO; DERWENT	OR	ON	2016/06/16 14:23

		20130222811-$ or US-20120222770-$ or US-20120222487-$ or US-20100254650-$).did. or (US-20060165344-$ or US-20060153487-$ or US-20060071158-$ or US-20060066839-$ or US-20060013534-$ or US-20060008196-$ or US-20050172721-$ or US-20040135075-$ or US-20040093950-$ or US-20010048071-$ or US-20060257066-$ or US-20050213869-$ or US-20050111793-$ or US-20020028034-$ or US-20060028636-$ or US-20050179889-$ or US-20060028637-$ or US-20050046859-$ or US-20050046860-$ or US-20060018586-$ or US-20050271395-$ or US-20050047706-$ or US-20040136652-$ or US-20030141440-$ or US-20010013934-$ or US-20070171400-$ or US-20070153839-$).did. or (US-20060120675-$).did. or (US-6243508-$ or US-7706641-$ or US-7189959-$ or US-6188824-$ or US-6169835-$ or US-6002646-$ or US-5862449-$ or US-5861974-$ or US-5485745-$ or US-5323114-$ or US-5061860-$ or US-7060964-$ or US-6626043-$ or US-6630658-$ or US-6597821-$ or US-6278811-$ or US-5845033-$ or US-5844927-$ or US-5767411-$ or US-5517022-$ or US-5218418-$ or US-5194847-$ or US-5010248-$ or US-4920261-$ or US-4904863-$ or US-6285806-$).did. or (US-6173091-$ or US-6043921-$ or US-5686986-$ or US-6816638-$ or US-6545760-$ or US-6057911-$ or US-5880824-$ or US-4983034-$ or US-6388741-$ or US-5506674-$ or US-5353110-$ or US-4968880-$ or US-4743753-$ or US-7274441-$ or US-7271884-$ or US-6778720-$ or US-6122305-$ or US-5892860-$ or US-5818585-$ or US-5815266-$ or US-5804713-$ or US-5754293-$ or US-5698848-$ or US-5696857-$ or US-5680489-$ or US-5513913-$ or US-5140154-$).did. or (US-4889986-$ or US-6122044-$ or US-5159400-$ or US-4826314-$ or US-4794249-$ or US-5627934-$ or US-4572950-$ or US-4905252-$ or US-6982997-$ or US-5452394-$ or US-6246816-$ or US-5177764-$ or US-4955034-$).did. or (WO-2009079730-$ or WO-9111042-$).did. or (JP-05315683-$).did. or (US-5194847-$ or WO-9608695-$ or EP-1359394-$ or WO-03093770-$ or US-7251023-$ or US-20060013534-$ or JP-08046574-$ or WO-2004034096-$ or WO-9111042-$ or WO-9110273-$ or GB-2372100-$ or WO-02065181-$ or GB-2372100-$ or US-5177764-$).did.					

S119	94	(oil or well) and S118	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/16 14:24
S120	23	iol near2 deposits	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/16 19:13
S121	3580035	oil	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/16 19:13
S122	15317	oil near2 deposit	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	ON	2016/06/16 19:14
S123	131	(US-20140327915-$ or US-20070039925-$ or US-20100060972-$ or US-20130338475-$ or US-20090022500-$ or US-20110075979-$ or US-20100200743-$ or US-20100175460-$ or US-20100150573-$ or US-20050082465-$ or US-20050077455-$ or US-20050002625-$ or US-20050002608-$ or US-20040257218-$ or US-20040213574-$ or US-20040146255-$ or US-20040129868-$ or US-20030021560-$ or US-20020090182-$ or US-20010019103-$ or US-20060156822-$ or US-20040165809-$ or US-20130222811-$ or US-20120222770-$ or US-20120222487-$ or US-20100254650-$).did. or (US-20060165344-$ or US-20060153487-$ or US-20060071158-$ or US-20060066839-$ or US-20060013534-$ or US-20060008196-$ or US-20050172721-$ or US-20040135075-$ or US-20040093950-$ or US-20010048071-$ or US-20060257066-$ or US-20050213869-$ or US-20050111793-$ or US-20020028034-$ or US-20060028636-$ or US-20050179889-$ or US-20060028637-$ or US-20050046859-$ or US-20050046860-$ or US-20060018586-$ or US-20050271395-$ or US-20050047706-$ or US-20040136652-$ or US-20030141440-$ or US-20010013934-$ or US-20070171400-$ or US-20070153839-$).did. or (US-20060120675-$).did. or (US-6243508-$ or US-7706641-$ or US-7189959-$ or US-6188824-$ or US-6169835-$ or	US-PGPUB; USPAT; EPO; JPO; DERWENT	OR	ON	2016/06/16 19:14

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C:\Users\sralis\Documents\EAST\Workspaces\14676170.wsp

Search Notes	**Application/Control No.** 14686161	**Applicant(s)/Patent Under Reexamination** PAYTON, ROBERT M
	Examiner STEPHEN J RALIS	**Art Unit** 3992

CPC- SEARCHED

Symbol	Date	Examiner
G01B11/162	5/23/2016	SR
G01L11/025	5/23/2016	SR
G01L1/242	5/23/2016	SR
G01M11/3118	5/23/2016	SR
G01D5/35383	5/23/2016	SR
G01M11/3172	5/23/2016	SR
G08B13/186	5/23/2016	SR

CPC COMBINATION SETS - SEARCHED

Symbol	Date	Examiner

US CLASSIFICATION SEARCHED

Class	Subclass	Date	Examiner

SEARCH NOTES

Search Notes	Date	Examiner
Text Searching Strategies (See EAST notes)	5/06/2016 - 7/29/2016	SR
Inventorr Search	6/16/2016	SR

INTERFERENCE SEARCH

US Class/ CPC Symbol	US Subclass / CPC Group	Date	Examiner

Customer No. 134845 23 November 2015

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants: ROBERT MICHAEL PAYTON
Serial No.: 14/686,161
Filed: 16 June 2015
Orig. Patent No.: 7,030,971
Orig. Issue Date: 18 Apr 2006
Attorney Docket No. 300099
For: **NATURAL SPAN REFLECTOMETRY WITH SENSING ZONE SEGMENTS**

REPLACEMENT PRELIMINARY AMENDMENT

Mail Stop Reissue
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

This replacement Preliminary Amendment is being filed to replace the preliminary amendment filed on 14 April 2015.

Amendments to the Specification: are reflected in the substitute paragraph provided on page 2 of this paper.

Amendments to the Abstract: is reflected in the substitute paragraph provided on page 4 of this paper.

Amendments to the Claims: are reflected in the listing of claims which begins on page 5 of this paper.

Amendments to the Drawings: None.

Remarks: begin on page 10 of this paper.

<u>AMENDMENTS TO THE SPECIFICATION</u>

Replace the title of the application at column 1, line 1, as follows: ~~NATURAL FIBER SPAN REFLECTOMETER PROVIDING A VIRTUAL SIGNAL SENSING ARRAY CAPABLITY~~ <u>NATURAL SPAN REFLECTOMETRY WITH SENSING ZONE SEGMENTS</u>.

Insert the following paragraph at column 1, line 3, following the title of the application, prior to the STATEMENT OF GOVERNMENT INTEREST:

This application is a <u>continuation</u> reissue of <u>U.S. Patent Application No. 14/190,478 which is an application for reissue of</u> ~~U.S. Patent Application No. 11/056,630 filed February 7, 2005, now~~ U.S. Patent No. 7,030,971 that claims the benefit of a provisional application, No. 60/599,437 which was filed on 6 August 2004, and which is entitled "Continuous Rayleigh Effect Sensor Backscattering Heterodyne Optical Sensor System" by Robert M. Payton.

At column 33, lines 10-37, replace the paragraph as follows:

The details, materials<u>,</u> ~~step~~ <u>steps</u> of operation and arrangement of parts herein have been described and illustrated in order to explain the nature of the invention. Many modifications in these are possible by those skilled in the art within the teachings herein of the invention. For example, while in system 2 the transformation from optical to r.f. signal takes place prior to processing by programmable correlation 23, it is within the skill of the art to design optical receiver 15 and correlator system 23 to have the transformation take place otherwise. Also, as an alternative to the previously described mechanism for phase locking laser 3 and 45, the laser optical wave on an optical path 39 can be passed through an acoustic-optic modulator, sometimes called a Bragg Cell. The diffracted optical wave exiting the acousto-optic modulator will be Doppler shifted by an impinging-driving RF wave, that is translated into a sound wave in the acousto-optic modulator, and the so-called Bragg shifted-diffracted optical wave will exit the acousti-optical ~~modudulator~~ modulator with an optical frequency equivalent to the phase locked laser 45. The acousto-optically generated lightwave, at an equivalent frequency of the phase locked laser 45, is sent along optical pathway 13 and becomes the local oscillator input to heterodyne photoreceiver 15. An acousto-optically frequency shifted version of the light in optical path 39 can therefore replace the phase locked light of coherent optical source 45. Accordingly it is to be understood that changes may be made by those skilled in the art within the principle and scope of the inventions expressed in the appended claims.

AMENDMENTS TO THE ABSTRACT

Replace the abstract with the following replacement abstract:

A distributed sensing system for an optical fiber span wherein the geometric arrangement of the span provides one or more sensing zones with different sensitivities. The span is interrogated with a series of radiated optical pulses. The back-scattered signals are detected from positions along the optical fiber span and the received signals are processed to provide a measurement representative of acoustic pressure waves incident on the span at the positions.

AMENDMENTS TO THE CLAIMS

The attached claims represent new claims in the continuation application, replacing the claims in the parent application.

Listing of Claims

1.-22. (Cancel).

23. (New) A system comprising:

a span of optical fiber having sensing zone segments wherein signals incident to said span have a property of inducing light path changes at sensing zone segments that result in a back-propagating signal wherein each zone segment has a specialized sensing function;

a light source operative to provide a continuous wave (CW) optical signal;

a modulator operative to modulate the CW optical signal with a reiterative autocorrelatable form of modulation, said modulator providing the modulated CW optical fiber to the span;

an optical receiver joined to said span and capable of receiving a retrieved optical signal returned therefrom, wherein the retrieved optical signal comprises back-propagating portions of the illumination from sensing zone segments, said receiver operative to produce a radio frequency (r.f.)

counterpart signal of the retrieved optical signal; and

a processor operative to detect a reiterative autocorrelatable form of modulation from the counterpart signal in a corresponding plurality of different timed relationships with respect to the reiterative autocorrelatable form of modulation of the CW optical signal to give at least one signal for each zone segment.

24. (New) The system of claim 23, wherein at least one zone segment of said span is helically disposed.

25. (New) The system of claim 23, wherein said span has a length L and said light source is a laser having the capability to generate a lightwave signal with sufficient stability to retain coherency in propagation along said span for a distance at least equal to two times the length L.

26. (New) The system of claim 25, wherein the length L of said span is at least about 5 km.

27. (New) The system of claim 23, wherein said light source is a planar, ring-type laser.

28. (New) The system of claim 23, wherein said span of optical fiber comprises a single mode fiber optic cable.

29. (New) The system of claim 23, wherein said span of optical fiber is made from the polarization preserving type of optical fiber.

30. (New) The system of claim 23, wherein said span of optical fiber has a coating made of a thermoplastic material having the combined characteristics of a low Young's modulus and a Poisson's ratio below that of natural rubber, wherein the coating enhances the longitudinal component of strain variation derived from an acoustic wave signal whose wave front is incident to the optical fiber span from a direction at least in part having a lateral component in the direction along which the wave front propagates.

31. (New) A method for sensing comprising the steps of:

providing a span of optical fiber wherein signals incident to the span induce light path changes at sensing zone segments of the span responsive to the signals resulting in a back-propagating signal;

illuminating the span with a modulated continuous wave (CW) optical signal with a reiterative autocorrelatable form of modulation;

receiving a retrieved optical signal from the span, wherein the retrieved optical signal comprises a back-propagating portions of the illumination from locations along the span in response to induced light path changes;

producing a radio frequency (r.f.) counterpart signal of the retrieved optical signal; and

detecting the reiterative autocorrelatable form of modulation from the counterpart signal in a corresponding plurality of different timed relationships with respect to the reiterative autocorrelatable form of modulation of the CW optical signal to provide signals from sensing zone segments of said span.

32. (New) The method of claim 31, wherein said step of providing the span includes providing at least one sensing zone segment of the span in a helical disposition.

33. (New) The method of claim 31, wherein the span of optical fiber span has a length L, and the light source is a laser having the capability to generate a lightwave signal with sufficient stability to substantially retain coherency in propagation along the span for a distance at least equal to two times length L.

34. (New) The method of claim 33, wherein the length L of said span is at least about 5 km.

35. (New) The method of claim 31, wherein said light source is a planar, ring-type laser.

36. (New) The method of claim 31, wherein said span of optical fiber comprises a single mode fiber optic cable.

37. (New) The method of claim 31, wherein said span of optical fiber is made from the polarization preserving type of optical fiber.

38. (New) The method of claim 31, wherein said span of optical fiber has a coating made of a thermoplastic material having the combined characteristics of a low Young's modulus and a Poisson's ratio below that of natural rubber, wherein the coating enhances the longitudinal component of strain variation derived from an acoustic wave signal whose wave front is incident to the optical fiber span from a direction at least in part having a lateral component in the direction along which the wave front propagates.

REMARKS / ARGUMENTS

Claims 1-22 are currently pending in the application.

New claims 23-38 are added. No new matter has been added. Claims 1-22 are canceled.

Concerning changes to the specification, the title and the abstract have been amended to more accurately reflect the claimed invention. The paragraph at col. 33, lines 10-37 is amended to correct typographical errors.

The amended claims are supported in the specification as described hereinafter. Claim 23 has the same scope as claim 21 of the parent application with an additional limitation narrower in scope than the claims of parent patent, U.S. Patent No. 7,030,971.

Reconsideration and allowance of the claims as amended is respectfully requested.

The Examiner is invited to telephone James M. Kasischke, Attorney for Applicant, at 401-832-3653 if, in the opinion of the Examiner, such a telephone call would serve to expedite the prosecution of the subject patent application.

Respectfully submitted,
ROBERT M. PAYTON

23 November 2015

By_/JAMES M. KASISCHKE/_
JAMES M. KASISCHKE
Attorney of Record
Reg. No. 36562

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	300099
	Application Number	
Title of Invention	Natural Span Reflectometry with Sensing Zone Segments	

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.

Secrecy Order 37 CFR 5.2

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Inventor Information:

Inventor 1 [Remove]

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Robert	Michael	Payton	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

City	Tomball	State/Province	TX	Country of Residence i	US

Mailing Address of Inventor:

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Address 2			
City	Tomball	**State/Province**	TX
Postal Code	77377	**Country i**	US

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. [Add]

Correspondence Information:

**Enter either Customer Number or complete the Correspondence Information section below.
For further information see 37 CFR 1.33(a).**

☐ **An Address is being provided for the correspondence Information of this application.**

Customer Number	134845	
Email Address		[Add Email] [Remove Email]

Application Information:

Title of the Invention	Natural Span Reflectometry with Sensing Zone Segments		
Attorney Docket Number	300099	**Small Entity Status Claimed**	☐
Application Type	Nonprovisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)		**Suggested Figure for Publication (if any)**	

Filing By Reference :

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	300099
	Application Number	

Title of Invention	Natural Span Reflectometry with Sensing Zone Segments

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country i

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32).
Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Please Select One:	◉ Customer Number	○ US Patent Practitioner	○ Limited Recognition (37 CFR 11.9)
Customer Number	134845		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing this information in the application data sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.
When referring to the current application, please leave the application number blank.

Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	Continuation of	14/190478	2014-02-26

Prior Application Status	Patented				Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)	Patent Number	Issue Date (YYYY-MM-DD)
14/190478	reissued of	11/056630	2005-02-07	7030971	2006-04-18

Prior Application Status	Expired		Remove

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	300099
	Application Number	
Title of Invention	Natural Span Reflectometry with Sensing Zone Segments	

Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
11/056630	Claims benefit of provisional	60/599437	2004-08-06

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button. Add

Foreign Priority Information:

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55. When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX) i the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

Remove

Application Number	Country i	Filing Date (YYYY-MM-DD)	Access Code i (if applicable)

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button. Add

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.
NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

Authorization to Permit Access:

☐ Authorization to Permit Access to the Instant Application by the Participating Offices

PTO/AIA/14 (07-14)
Approved for use through 04/30/2017. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	300099
	Application Number	

Title of Invention	Natural Span Reflectometry with Sensing Zone Segments

If checked, the undersigned hereby grants the USPTO authority to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the World Intellectual Property Office (WIPO), and any other intellectual property offices in which a foreign application claiming priority to the instant patent application is filed access to the instant patent application. See 37 CFR 1.14(c) and (h). This box should not be checked if the applicant does not wish the EPO, JPO, KIPO, WIPO, or other intellectual property office in which a foreign application claiming priority to the instant patent application is filed to have access to the instant patent application.

In accordance with 37 CFR 1.14(h)(3), access will be provided to a copy of the instant patent application with respect to: 1) the instant patent application-as-filed; 2) any foreign application to which the instant patent application claims priority under 35 U.S.C. 119(a)-(d) if a copy of the foreign application that satisfies the certified copy requirement of 37 CFR 1.55 has been filed in the instant patent application; and 3) any U.S. application-as-filed from which benefit is sought in the instant patent application.

In accordance with 37 CFR 1.14(c), access may be provided to information concerning the date o f filing this Authorization.

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1 Remove

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

Clear

○ Assignee ○ Legal Representative under 35 U.S.C. 117 ○ Joint Inventor

○ Person to whom the inventor is obligated to assign. ○ Person who shows sufficient proprietary interest

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor :

If the Applicant is an Organization check here. ☐

Prefix	**Given Name**	Middle Name	**Family Name**	Suffix

PTO/AIA/14 (07-14)
Approved for use through 04/30/2017. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	300099
	Application Number	

Title of Invention	Natural Span Reflectometry with Sensing Zone Segments

Mailing Address Information For Applicant:			
Address 1			
Address 2			
City		**State/Province**	
Country i		Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Applicant Data may be generated within this form by selecting the Add button. Add

Assignee Information including Non-Applicant Assignee Information:

Providing assignment information in this section does not subsitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Assignee 1

Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication . An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.

Remove

If the Assignee or Non-Applicant Assignee is an Organization check here. ☒

Organization Name	The United States of America as represented by the Secretary of the Navy

Mailing Address Information For Assignee including Non-Applicant Assignee:			
Address 1	Naval Undersea Warfare Center Division Newport		
Address 2	1176 Howell Street, Code 00L, Bldg 102T		
City	Newport	**State/Province**	RI
Country i	US	Postal Code	02841
Phone Number		Fax Number	
Email Address			

Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button. Add

Signature:

Remove

NOTE: This form must be signed in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications.

Signature	/James M. Kasischke/	Date (YYYY-MM-DD)	2015-11-17

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	300099
	Application Number	

Title of Invention	Natural Span Reflectometry with Sensing Zone Segments

First Name	James	Last Name	Kasischke	Registration Number	36562
Additional Signature may be generated within this form by selecting the Add button.				Add	

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these records.

2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.

3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.

4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).

5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent C o o p eration Treaty.

6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).

7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.

8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspections or an issued patent.

9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	300099
First Named Inventor	Robert Michael Payton
Title	Natural...Segments
Express Mail Label No.	

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: **Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450**

1. ☐ **Fee Transmittal Form** (PTO/SB/17 or equivalent)
2. ☐ **Applicant asserts small entity status.** See 37 CFR 1.27
3. ☐ **Applicant certifies micro entity status.** See 37 CFR 1.29. Applicant must attach form PTO/SB/15A or B or equivalent.
4. ☐ **Specification** [*Total Pages* ____________] Both the claims and abstract must start on a new page. *(See MPEP § 608.01(a) for information on the preferred arrangement)*
5. ☐ **Drawing(s)** (35 U.S.C. 113) [*Total Sheets* ____________]
6. **Inventor's Oath or Declaration** [*Total Pages* ____________] *(including substitute statements under 37 CFR 1.64 and assignments serving as an oath or declaration under 37 CFR 1.63(e))*
   - a. ☐ Newly executed (original or copy)
   - b. ☐ A copy from a prior application (37 CFR 1.63(d))
7. ☑ **Application Data Sheet** ** See note below.* See 37 CFR 1.76 (PTO/AIA/14 or equivalent)
8. **CD-ROM or CD-R** in duplicate, large table, or Computer Program (*Appendix*)
   - ☐ Landscape Table on CD
9. **Nucleotide and/or Amino Acid Sequence Submission** (*if applicable, items a. – c. are required*)
   - a. ☐ Computer Readable Form (CRF)
   - b. ☐ Specification Sequence Listing on:
     - i. ☐ CD-ROM or CD-R (2 copies); or
     - ii. ☐ Paper
   - c. ☐ Statements verifying identity of above copies

ACCOMPANYING APPLICATION PAPERS

10. ☐ **Assignment Papers** (cover sheet & document(s)) Name of Assignee ____________
11. ☐ **37 CFR 3.73(c) Statement** (*when there is an assignee*) ☐ **Power of Attorney**
12. ☐ **English Translation Document** (*if applicable*)
13. ☐ **Information Disclosure Statement** (PTO/SB/08 or PTO-1449)
    - ☐ Copies of citations attached
14. ☑ **Preliminary Amendment**
15. ☐ **Return Receipt Postcard** (*MPEP § 503*) (*Should be specifically itemized*)
16. ☐ **Certified Copy of Priority Document(s)** (*if foreign priority is claimed*)
17. ☐ **Nonpublication Request** Under 35 U.S.C. 122(b)(2)(B)(i). Applicant must attach form PTO/SB/35 or equivalent.
18. ☑ **Other:** Remarks: The Preliminary Amendment and ADS are replacements of those previous filed

    The USPTO has authorization to credit or charge any additional fees to deposit account 14-0590

***Note**: (1) Benefit claims under 37 CFR 1.78 and foreign priority claims under 1.55 **must** be included in an Application Data Sheet (ADS).
(2) For applications filed under 35 U.S.C. 111, the application must contain an ADS specifying the applicant if the applicant is an assignee, person to whom the inventor is under an obligation to assign, or person who otherwise shows sufficient proprietary interest in the matter. See 37 CFR 1.46(b).

19. CORRESPONDENCE ADDRESS

☑ The address associated with Customer Number: 134845 **OR** ☐ Correspondence address below

Name					
Address					
City		State		Zip Code	
Country		Telephone		Email	

Signature	/James M. Kasischke/	Date	11/24/15
Name (Print/Type)	James M. Kasischke	Registration No. (Attorney/Agent)	36562

Privacy Act Statement

The **Privacy Act of 1974 (P.L. 93-579)** requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (*i.e.*, GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Electronic Acknowledgement Receipt

EFS ID:	24174529
Application Number:	14686161
International Application Number:	
Confirmation Number:	5544
Title of Invention:	NATURAL SPAN REFLECTOMETRY WITH SENSING ZONE SEGMENTS
First Named Inventor/Applicant Name:	Robert M Payton
Customer Number:	134845
Filer:	James Martin Kasischke
Filer Authorized By:	
Attorney Docket Number:	300099
Receipt Date:	24-NOV-2015
Filing Date:	16-JUN-2015
Time Stamp:	13:56:24
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Preliminary Amendment	300099RepPreAm.pdf	166690 9fbbe35e25b702eced4980e99f85f49f116f4462	no	10

Warnings:

Information:

2	Application Data Sheet	300099RepAm2ADS.pdf	1819350 f87f46550a0a2b4ff370af1360a62ec763551a81	no	7
Warnings:					
Information:					
3	Transmittal Letter	Transmittalform.pdf	276451 f9cbb84ba1297c843496dddf799d8131a607f339	no	2
Warnings:					
Information:					
			Total Files Size (in bytes):	2262491	

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

PTO/SB/06 (09-11)
Approved for use through 1/31/2014. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 14/686,161	Filing Date 06/16/2015	☐ To be Mailed

ENTITY: ☒ LARGE ☐ SMALL ☐ MICRO

APPLICATION AS FILED – PART I

FOR	NUMBER FILED (Column 1)	NUMBER EXTRA (Column 2)	RATE ($)	FEE ($)
☐ BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	
☐ SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	
☐ EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	minus 20 =	*	X $ =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*	X $ =	
☐ APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			
☐ MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	

APPLICATION AS AMENDED – PART II

AMENDMENT 11/24/2015	CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	RATE ($)	ADDITIONAL FEE ($)
Total (37 CFR 1.16(i))	* 16	Minus	** 20	= 0	x $80 =	0
Independent (37 CFR 1.16(h))	* 2	Minus	***3	= 0	x $420 =	0
☐ Application Size Fee (37 CFR 1.16(s))						
☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
					TOTAL ADD'L FEE	**0**

AMENDMENT	CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	RATE ($)	ADDITIONAL FEE ($)
Total (37 CFR 1.16(i))	*	Minus	**	=	X $ =	
Independent (37 CFR 1.16(h))	*	Minus	***	=	X $ =	
☐ Application Size Fee (37 CFR 1.16(s))						
☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
					TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

LDRC
/CHERRI FITZGERALD/

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	PATENT NUMBER	GROUP ART UNIT	FILE WRAPPER LOCATION
14/686,161		3992	e

PAIR Correspondence Address/Fee Address Change

The following fields have been changed to Customer Number 134845 on 08/17/2015 via Private PAIR in view of the certification copied below that authorized the change.

- Correspondence Address

The address for Customer Number 134845 is:
134845
NUWCDIVNPT / ADELOS
1176 HOWELL STREET, Code 00L
Bldg. 102T
NEWPORT, RI 02841

I certify, in accordance with 37 CFR 1.4(d)(4) that I am:

An attorney or Agent of Record registered to practice before the Patent and Trademark Office who has been given power of attorney in this application

Signature:	/James M. Kasischke/
Name:	James M. Kasischke
Registration Number:	36562

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
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14/686,161		3992	e

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The address for Customer Number 134845 is:
134845
NUWCDIVNPT / ADELOS
1176 HOWELL STREET, Code 00L
Bldg. 102T
NEWPORT, RI 02841

I certify, in accordance with 37 CFR 1.4(d)(4) that I am:

An attorney or Agent of Record registered to practice before the Patent and Trademark Office who has been given power of attorney in this application

Signature:	/James M. Kasischke/
Name:	James M. Kasischke
Registration Number:	36562

PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 14/686,161

APPLICATION AS FILED - PART I

FOR	NUMBER FILED (Column 1)	NUMBER EXTRA (Column 2)	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A			N/A	280
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A			N/A	600
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	2160
TOTAL CLAIMS (37 CFR 1.16(i))	16 minus 20 =	*			OR	x 80 =	0.00
INDEPENDENT CLAIMS (37 CFR 1.16(h))	2 minus 3 =	*				x 420 =	0.00
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).						0.00
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))							0.00
			TOTAL			TOTAL	3040

* If the difference in column 1 is less than zero, enter "0" in column 2.

APPLICATION AS AMENDED - PART II

AMENDMENT A		CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

AMENDMENT B		CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	RATE($)	ADDITIONAL FEE($)	OR	RATE($)	ADDITIONAL FEE($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

UNITED STATES PATENT AND TRADEMARK OFFICE

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United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
14/686,161	06/16/2015	2877	3180	300099	16	2

CONFIRMATION NO. 5544

FILING RECEIPT

OC000000075933699

23523
NAVAL UNDERSEA WARFARE CENTER
DIVISION NEWPORT
1176 HOWELL STREET, Code 00L
Bldg. 102T
NEWPORT, RI 02841

Date Mailed: 06/24/2015

Receipt is acknowledged of this reissue patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Inventor(s)

Robert M Payton, Tomball, TX;

Applicant(s)

Robert M Payton, Tomball, TX;

Assignment For Published Patent Application

The United States of America represented by the Se, Washington, DC

Power of Attorney: The patent practitioners associated with Customer Number 23523

Domestic Priority data as claimed by applicant

This application is a CON of 14/190,478 02/26/2014
which is a REI of 11/056,630 02/07/2005 PAT 7030971
which claims benefit of 60/599,437 08/06/2004

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

If Required, Foreign Filing License Granted: 06/24/2015

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 14/686,161**

Projected Publication Date: None, application is not eligible for pre-grant publication

Non-Publication Request: No

Early Publication Request: No

Title

Natural Span Reflectometry with Sensing Zone Segments

Preliminary Class

356

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

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Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

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Customer No. 23523 16 June 2015

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants: ROBERT MICHAEL PAYTON Orig. Patent No.: 7,030,971
Serial No.: 14/686,161 Orig. Issue Date: 18 Apr 2006
Filed: 14 April 2015 Attorney Docket No. 300099
For: **NATURAL SPAN REFLECTOMETRY WITH SENSING ZONE SEGMENTS**

RESPONSE TO PRE-EXAM FORMALITIES NOTICE

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

In response to the Notice of Incomplete Reissue Application mailed 16 April 2015, Applicant is transmitting a copy of the original patent, U.S. Patent No. 7,030,971. This is an official copy of the patent downloaded from the U.S. Patent and Trademark Office's website. This is attached as exhibit 1. Please contact the undersigned if this fails to satisfy the requirements for filing a reissue patent application.

Concerning the assertion that the drawings are missing, Applicant is transmitting a complete set of clean drawings. These are attached as exhibit 2.

Concerning the assertion that the consent of the assignee is missing, Applicant is transmitting a completed Consent of Assignee form, PTO/AIA/53 (09-12). This is attached as exhibit 3.

Lastly a newly executed Declaration by the Assignee is attached as exhibit 4.

Please contact the undersigned in order to specifically indicate the defects in this consent.

The Examiner is invited to telephone James M. Kasischke, Attorney for Applicant, at 401-832-3653 to address matters concerning this application.

Respectfully submitted,
ROBERT M. PAYTON

16 June 2015

By_/JAMES M. KASISCHKE/_
JAMES M. KASISCHKE
Attorney of Record
Reg. No. 36562

Exhibits:

(1) Copy of US Patent 7,030,971
(2) Clean Copy of Drawings
(3) Consent of Assignee Form
(4) New executed Declaration by the Assignee

US007030971B1

(12) **United States Patent**
Payton

(10) **Patent No.: US 7,030,971 B1**
(45) **Date of Patent: Apr. 18, 2006**

(54) **NATURAL FIBER SPAN REFLECTOMETER PROVIDING A VIRTUAL SIGNAL SENSING ARRAY CAPABILITY**

(75) Inventor: **Robert Michael Payton**, Portsmouth, RI (US)

(73) Assignee: **The United States of America represented by the Secretary of the Navy**, Washington, DC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **11/056,630**

(22) Filed: **Feb. 7, 2005**

Related U.S. Application Data

(60) Provisional application No. 60/599,437, filed on Aug. 6, 2004.

(51) **Int. Cl.**
G01L 1/24 (2006.01)
G01B 9/02 (2006.01)

(52) **U.S. Cl.** **356/35.5**; 356/478; 356/484

(58) **Field of Classification Search** 356/35.5, 356/73.1, 477, 478, 484; 367/140, 141
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,194,847 A 3/1993 Taylor et al.
5,686,986 A * 11/1997 Li et al. 356/73.1
6,043,921 A 3/2000 Payton
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6,285,806 B1 9/2001 Kersey et al.

OTHER PUBLICATIONS

R. Hughes and J. Jarzynski, "Static Pressure Sensitivity Amplification in Interferometric Fiber-Optic Hydrophones", Applied Optics, Jan. 1, 1980, vol. 19., No. 1, USA.

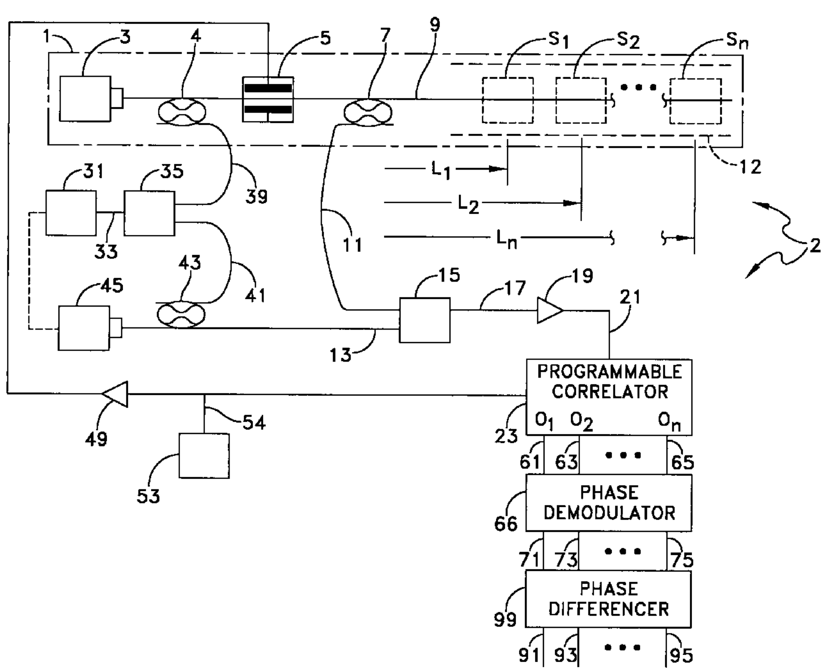
* cited by examiner

Primary Examiner—Gregory J. Toatley, Jr.
Assistant Examiner—Michael A. Lyons
(74) *Attorney, Agent, or Firm*—James M. Kasischke; Jean-Paul A. Nasser; Michael P. Stanley

(57) **ABSTRACT**

A CW lightwave modulated by a continuously reiterated binary pseudorandom code sequence is launched into an end of a span of ordinary optical fiber cable. Portions of the launched lightwave back propagate to the launch end from a continuum of locations along the span because of innate fiber properties including Rayleigh scattering. This is picked off the launch end and heterodyned to produce a r.f. beat signal. The r.f. beat signal is processed by a plurality (which can be thousands) of correlator type binary pseudonoise code sequence demodulators respectively operated in different delay time relationships to the timing base of the reiterated modulation sequences. The outputs of the demodulators provide r.f. time-domain reflectometry outputs representative of signals (e.g., acoustic pressure waves) incident to virtual sensors along the fiber at positions corresponding to the various time delay relationships.

22 Claims, 13 Drawing Sheets



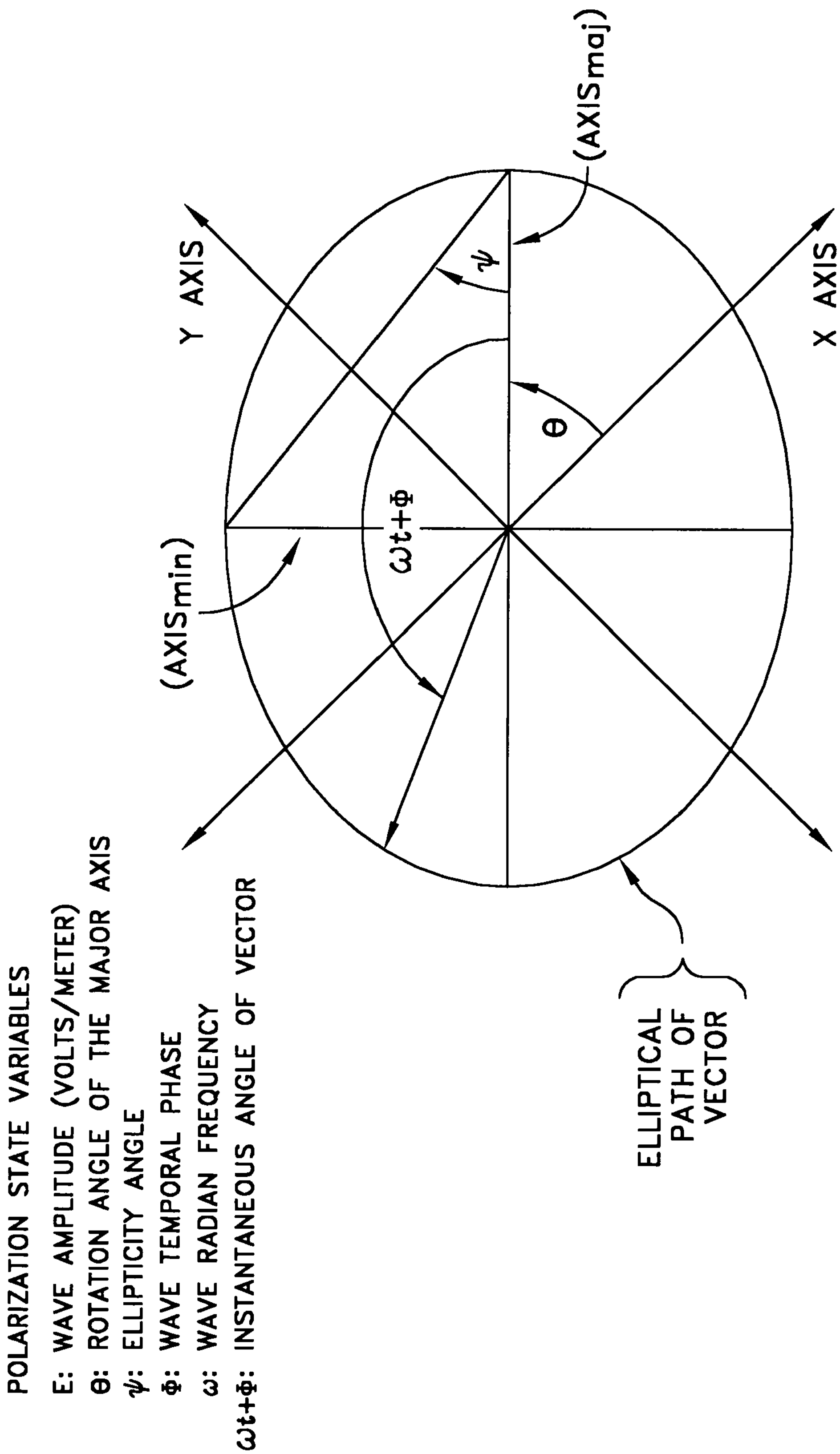

POLARIZATION STATE VARIABLES
E: WAVE AMPLITUDE (VOLTS/METER)
Θ: ROTATION ANGLE OF THE MAJOR AXIS
ψ: ELLIPTICITY ANGLE
Φ: WAVE TEMPORAL PHASE
ω: WAVE RADIAN FREQUENCY
ωt+Φ: INSTANTANEOUS ANGLE OF VECTOR
(AXISmaj)
(AXISmin)
Y AXIS
X AXIS
ψ
Θ
ωt+Φ
ELLIPTICAL PATH OF VECTOR

FIG. 1

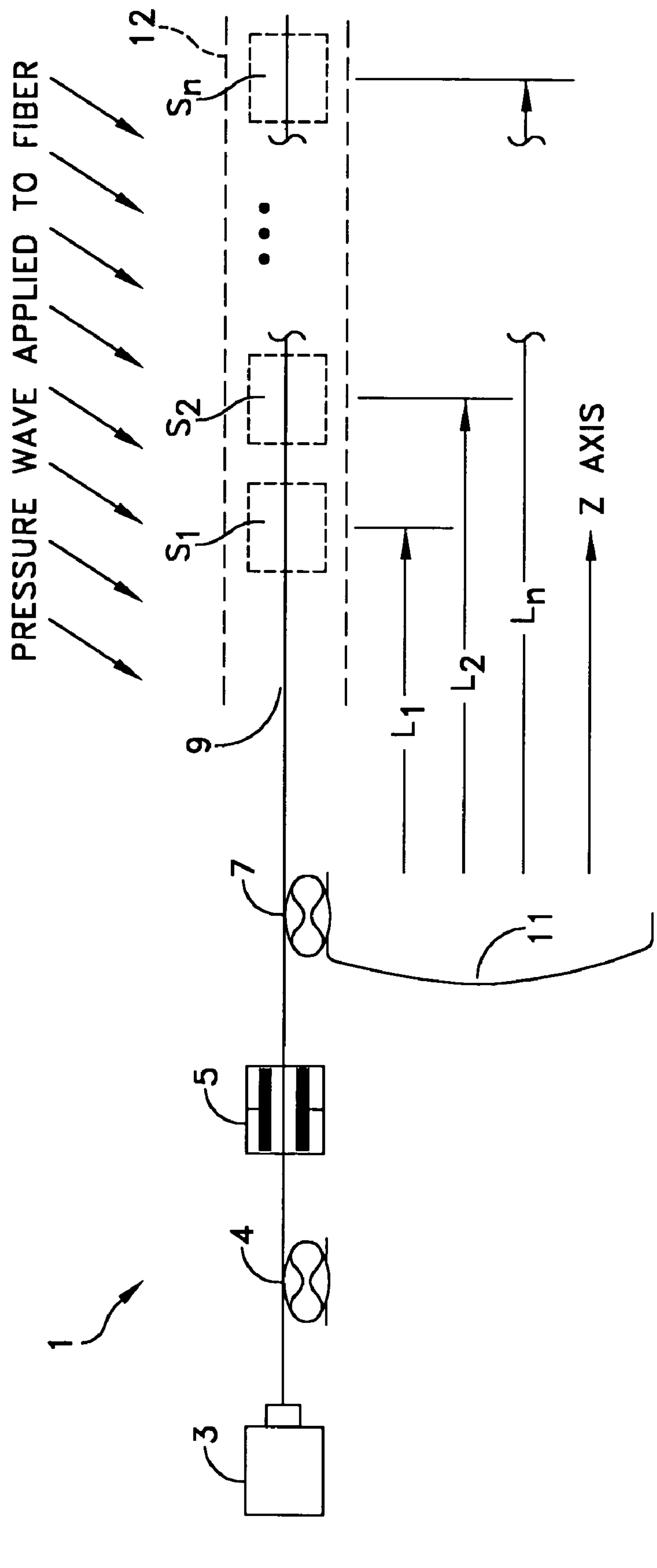

PRESSURE WAVE APPLIED TO FIBER
12
S_n
S_2
S_1
9
L_1
L_2
L_n
Z AXIS
7
11
5
4
1
3

FIG. 2

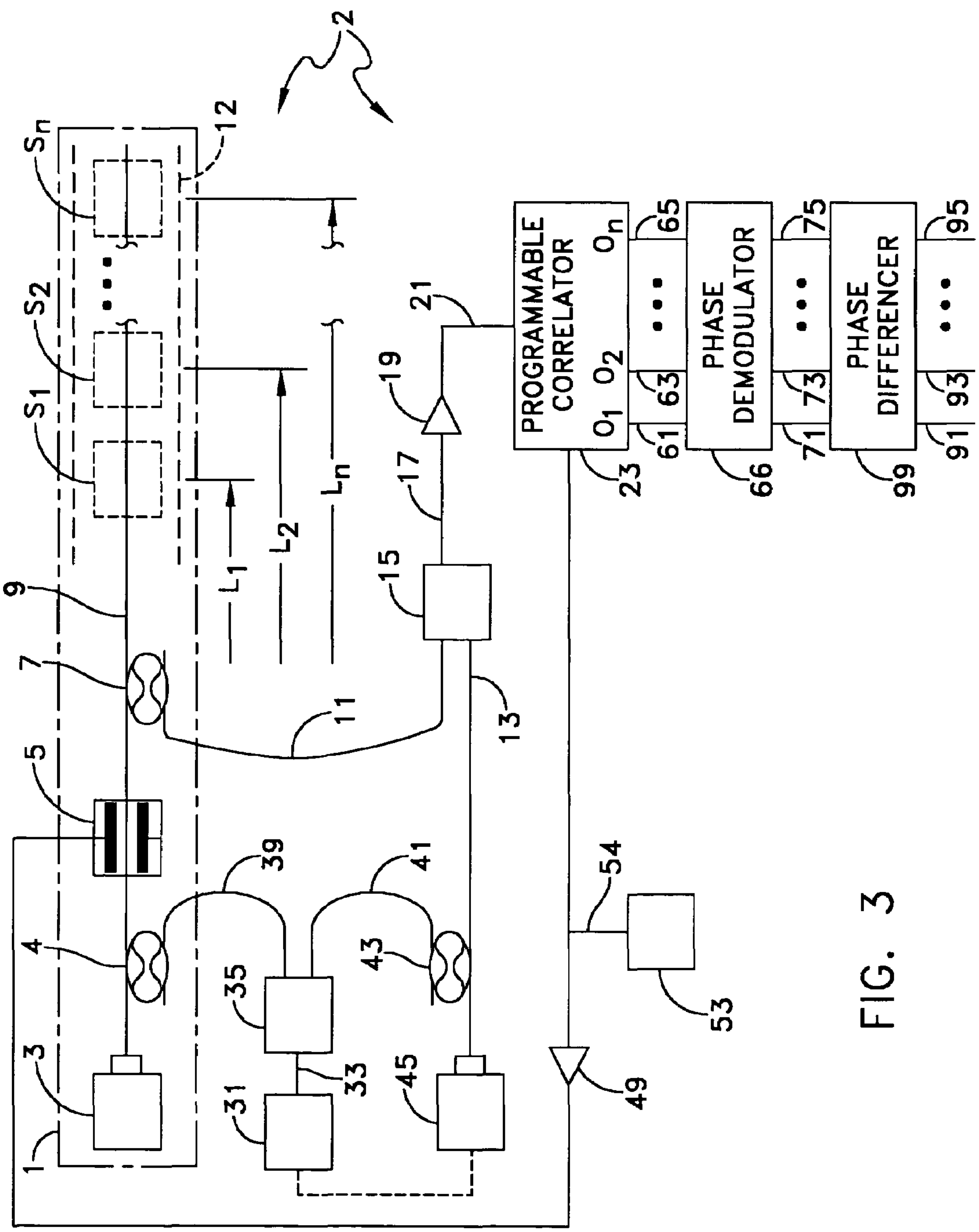

PROGRAMMABLE CORRELATOR
PHASE DEMODULATOR
PHASE DIFFERENCER
O_1
O_2
O_n
S_1
S_2
S_n
L_1
L_2
L_n
1
2
3
4
5
7
9
11
12
13
15
17
19
21
23
31
33
35
39
41
43
45
49
53
54
61
63
65
66
71
73
75
91
93
95
99

FIG. 3

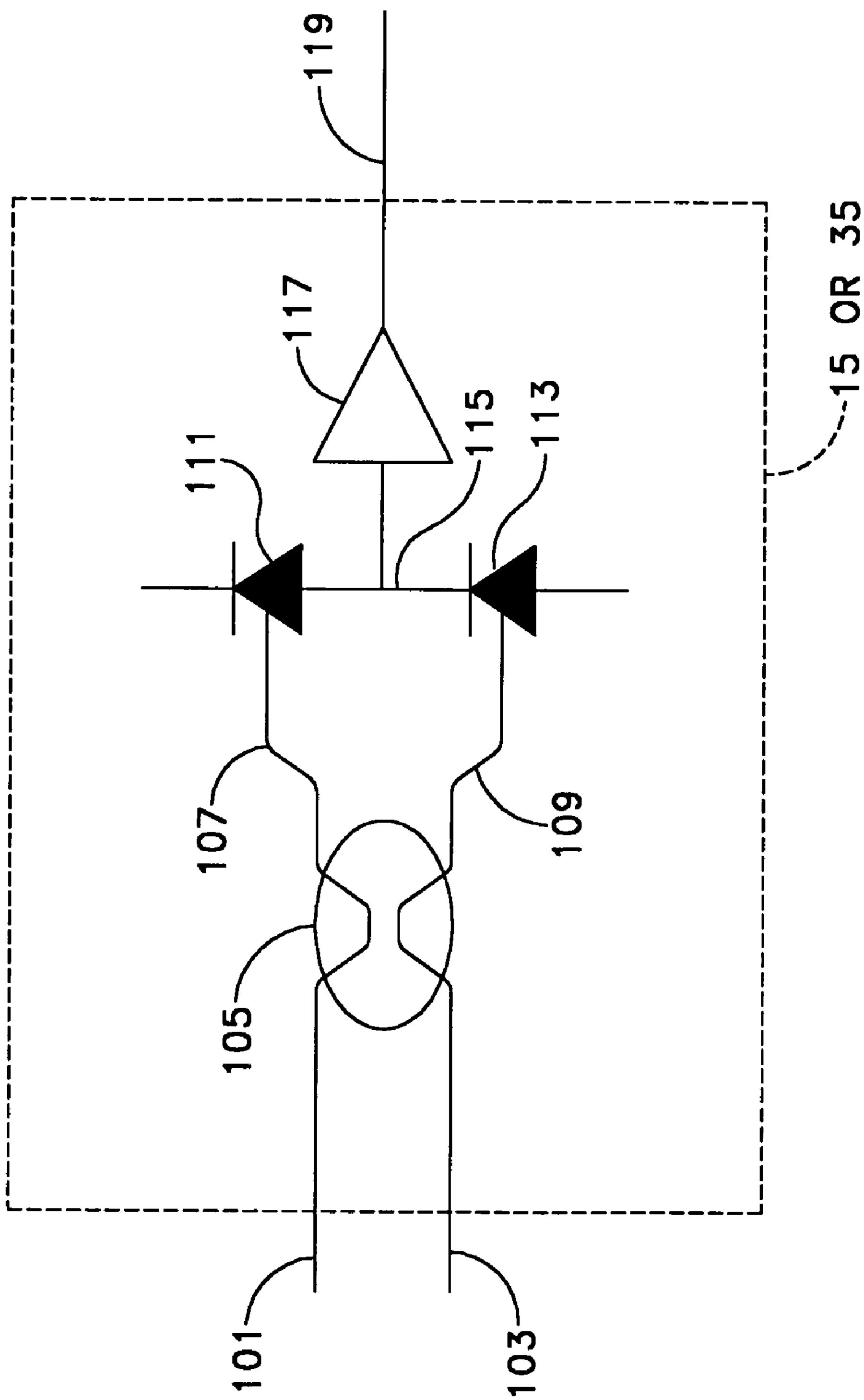


FIG. 4

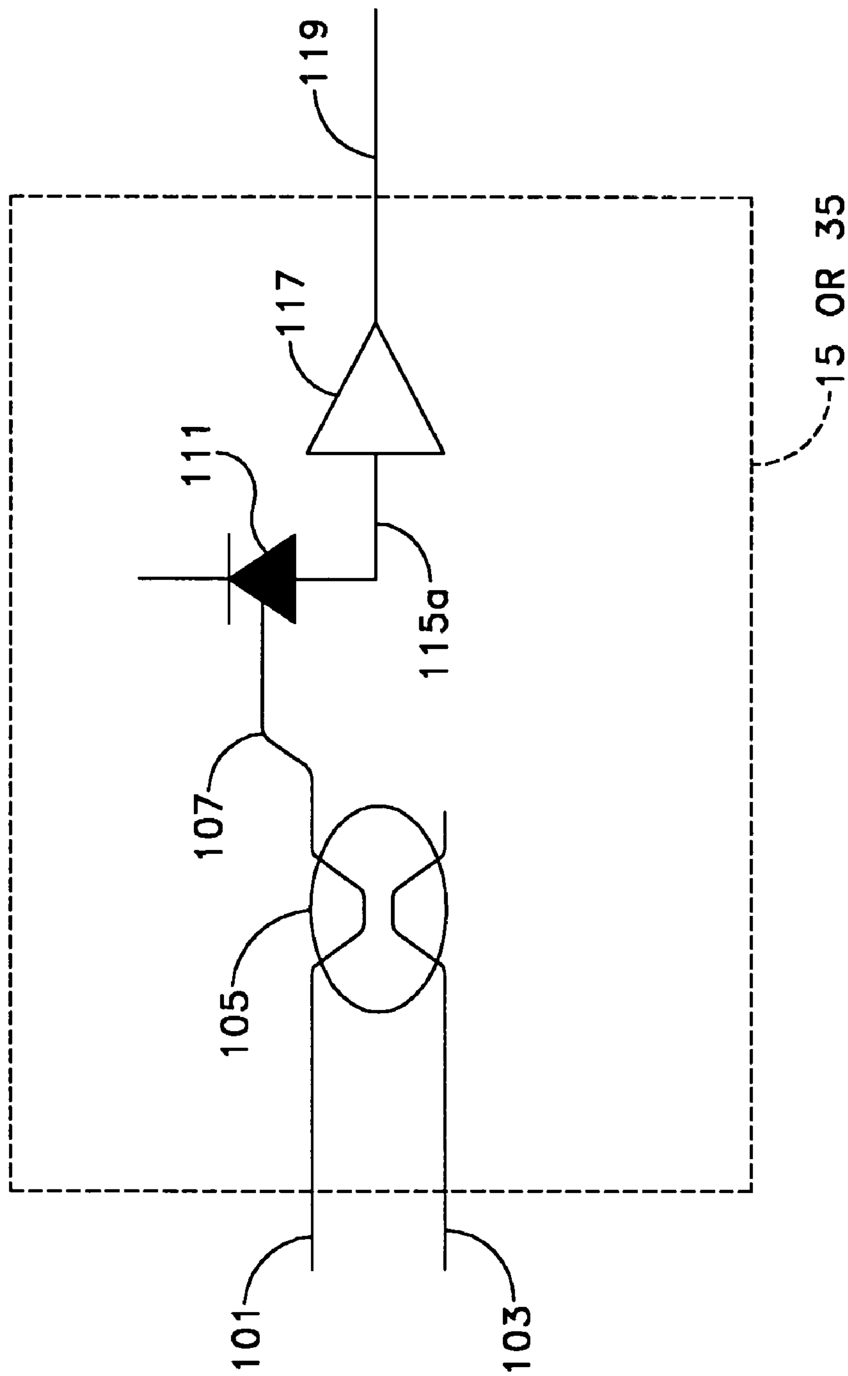
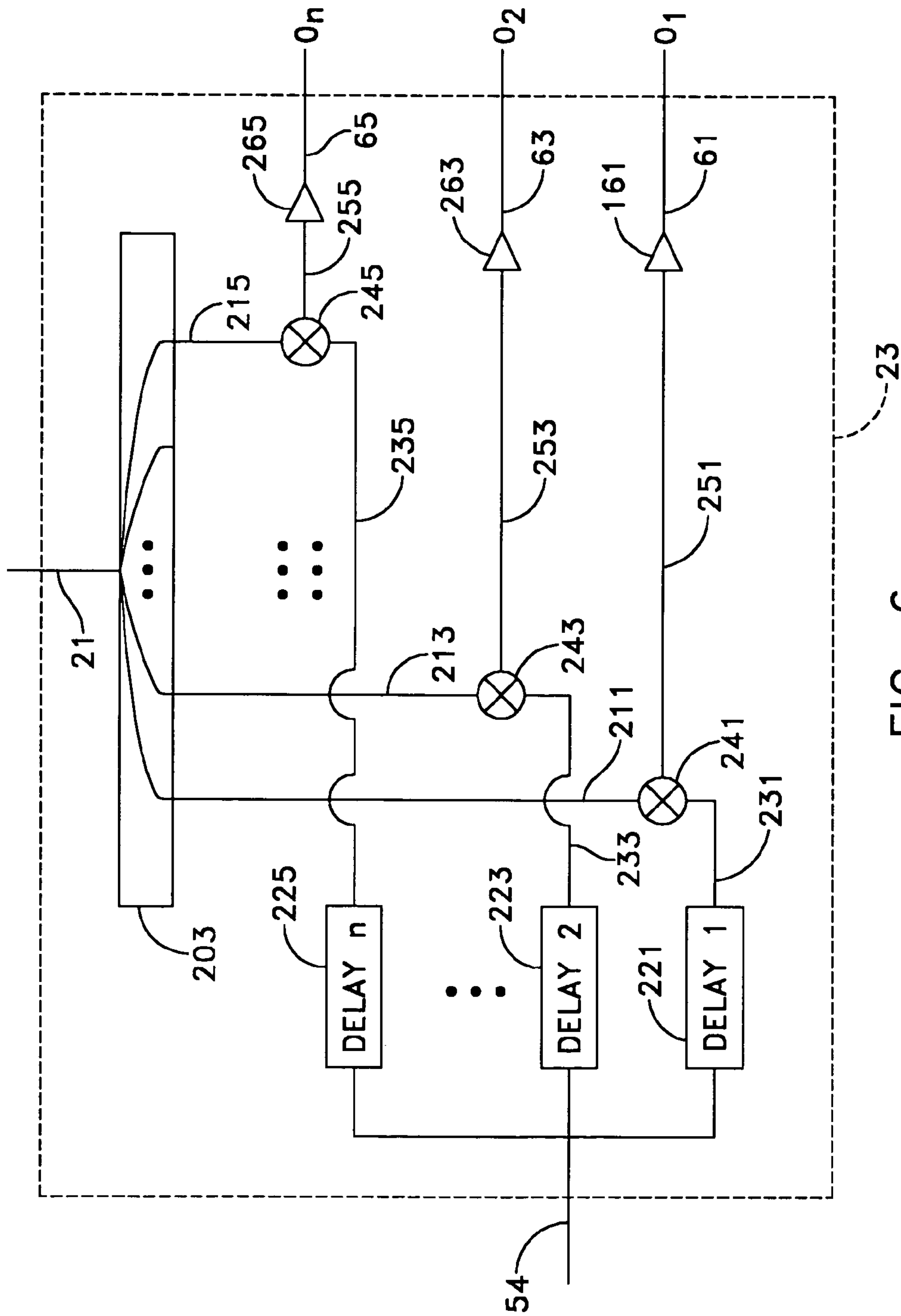


FIG. 5



DELAY 1
DELAY 2
DELAY n
21
23
54
61
63
65
161
203
211
213
215
221
223
225
231
233
235
241
243
245
251
253
255
263
265
0n
02
01

FIG. 6

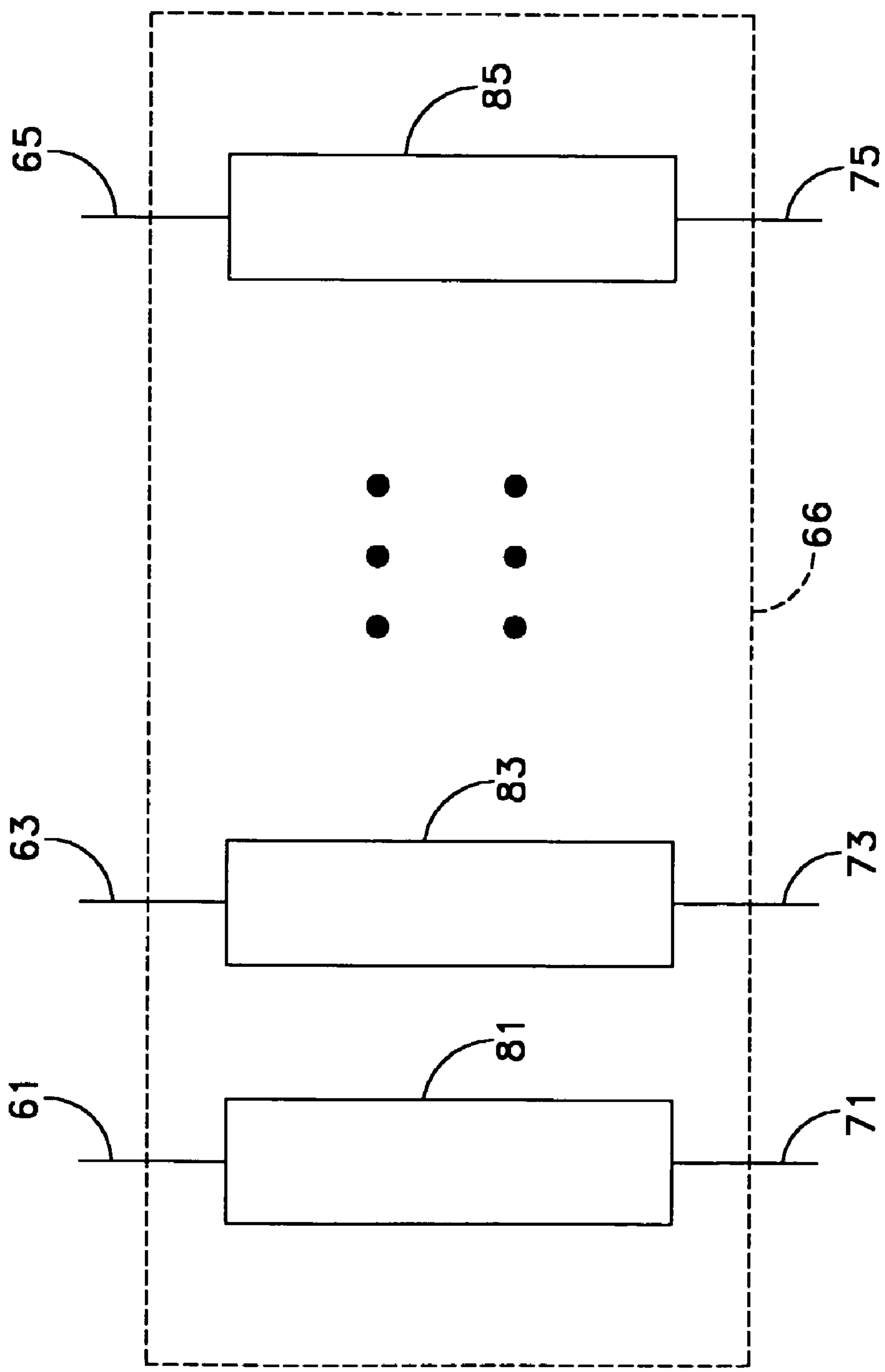


FIG. 7

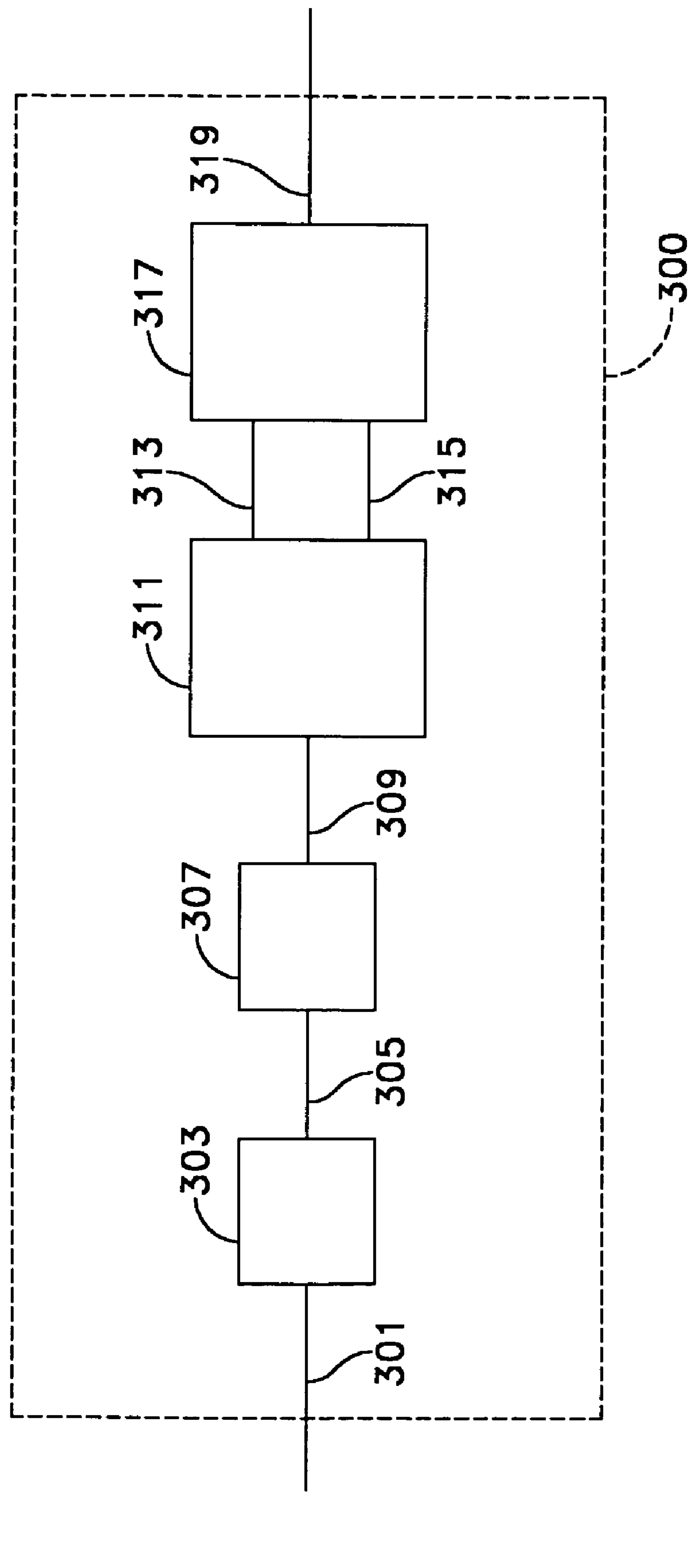


FIG. 8

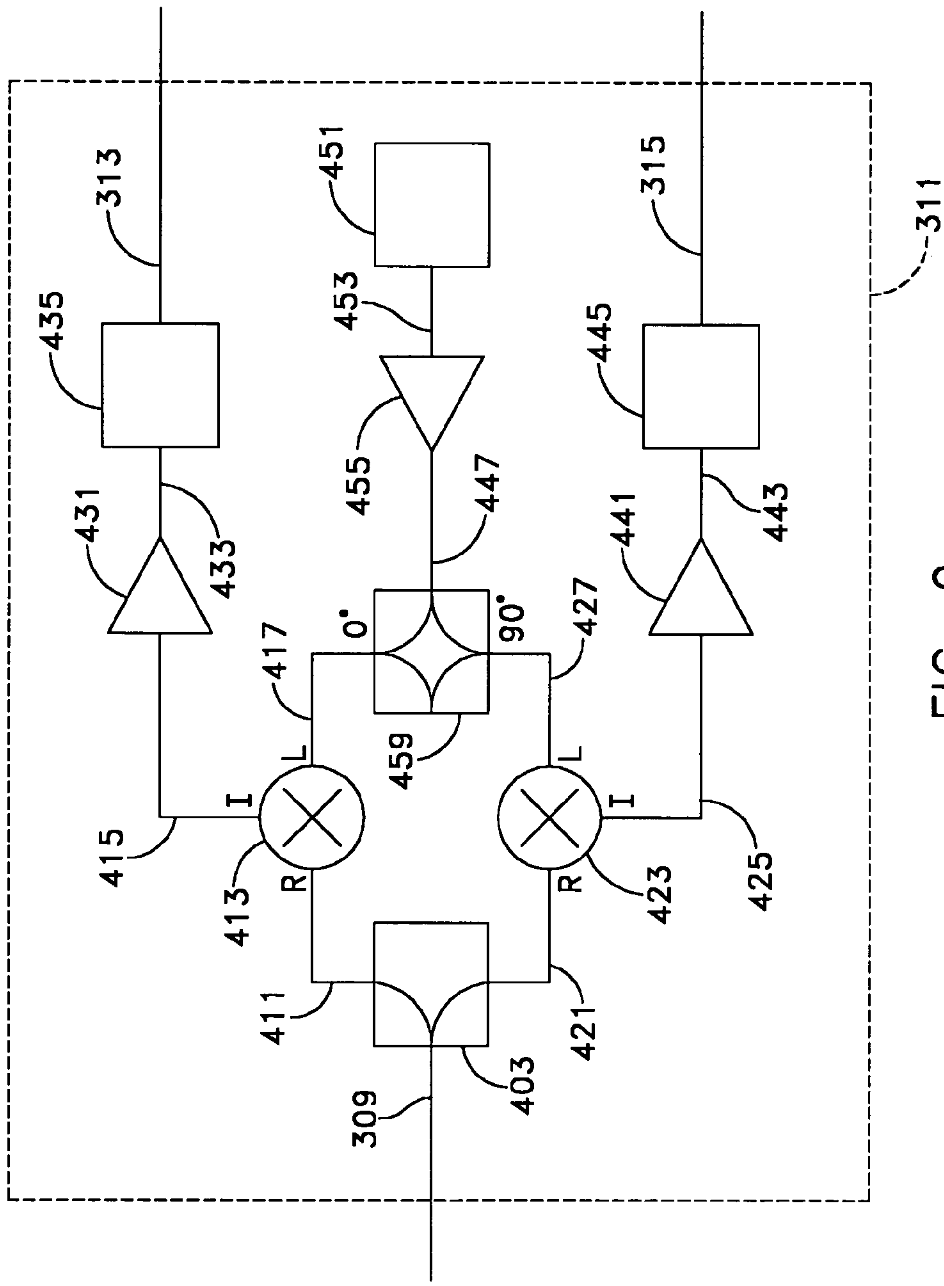

313
451
315
311
435
453
445
455
447
431
433
441
443
417
0°
90°
427
459
L
L
I
I
415
413
R
R
423
425
411
421
403
309

FIG. 9

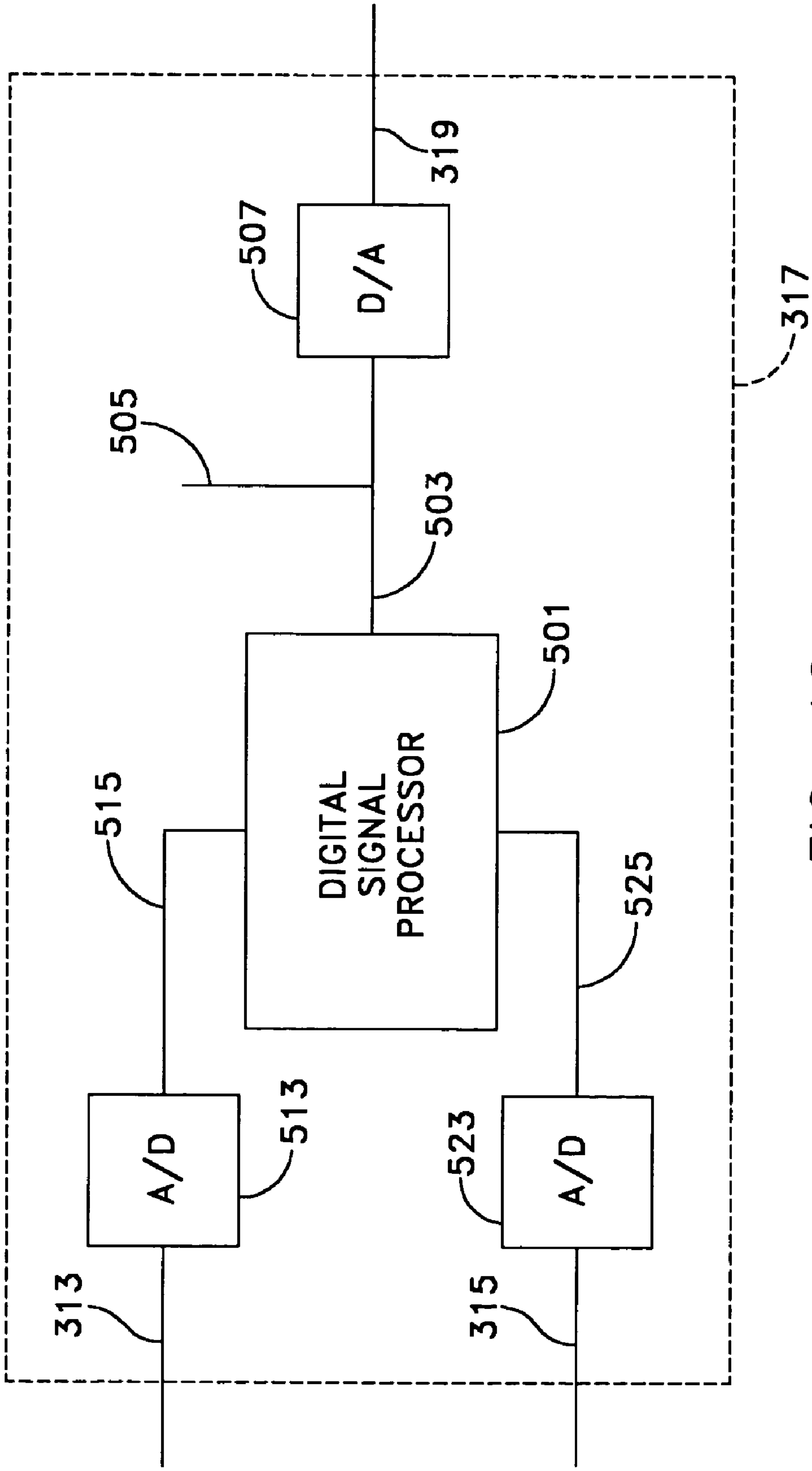

319
507
D/A
317
505
503
501
DIGITAL SIGNAL PROCESSOR
515
525
A/D
513
523
A/D
313
315

FIG. 10

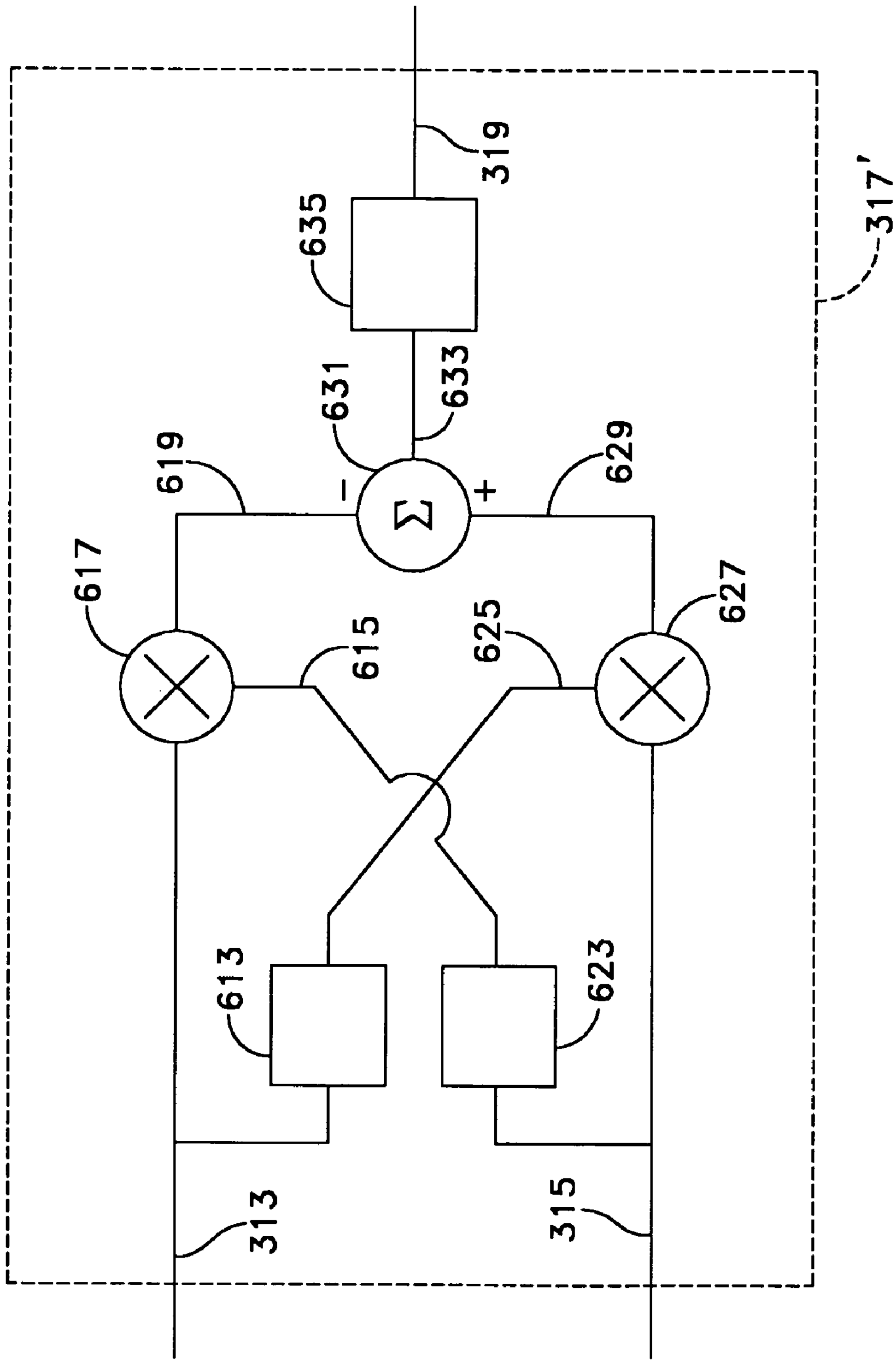


FIG. 11

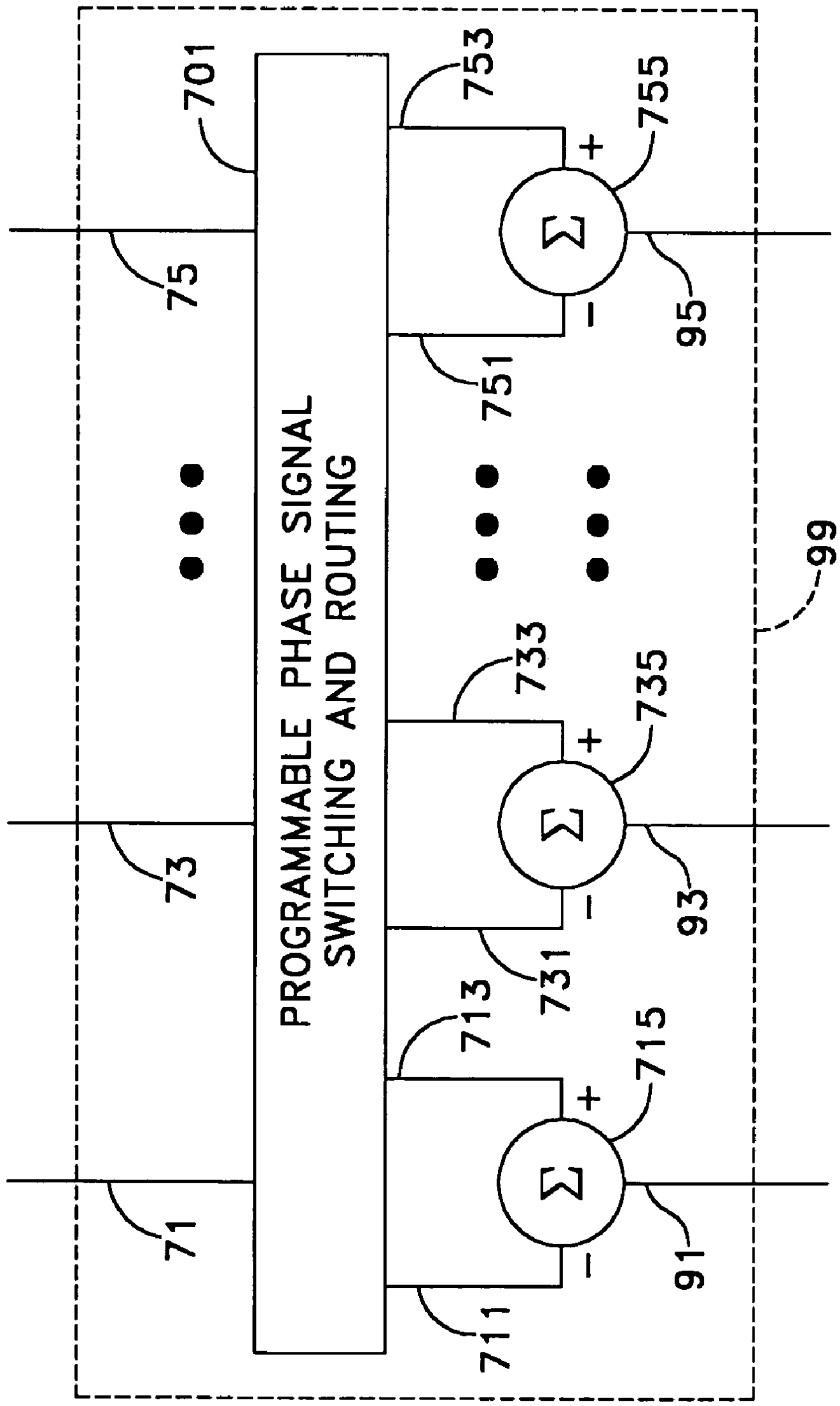

PROGRAMMABLE PHASE SIGNAL
SWITCHING AND ROUTING
701
71
73
75
711
713
715
731
733
735
751
753
755
91
93
95
99
Σ
Σ
Σ
+
-
+
-
+
-

FIG. 12

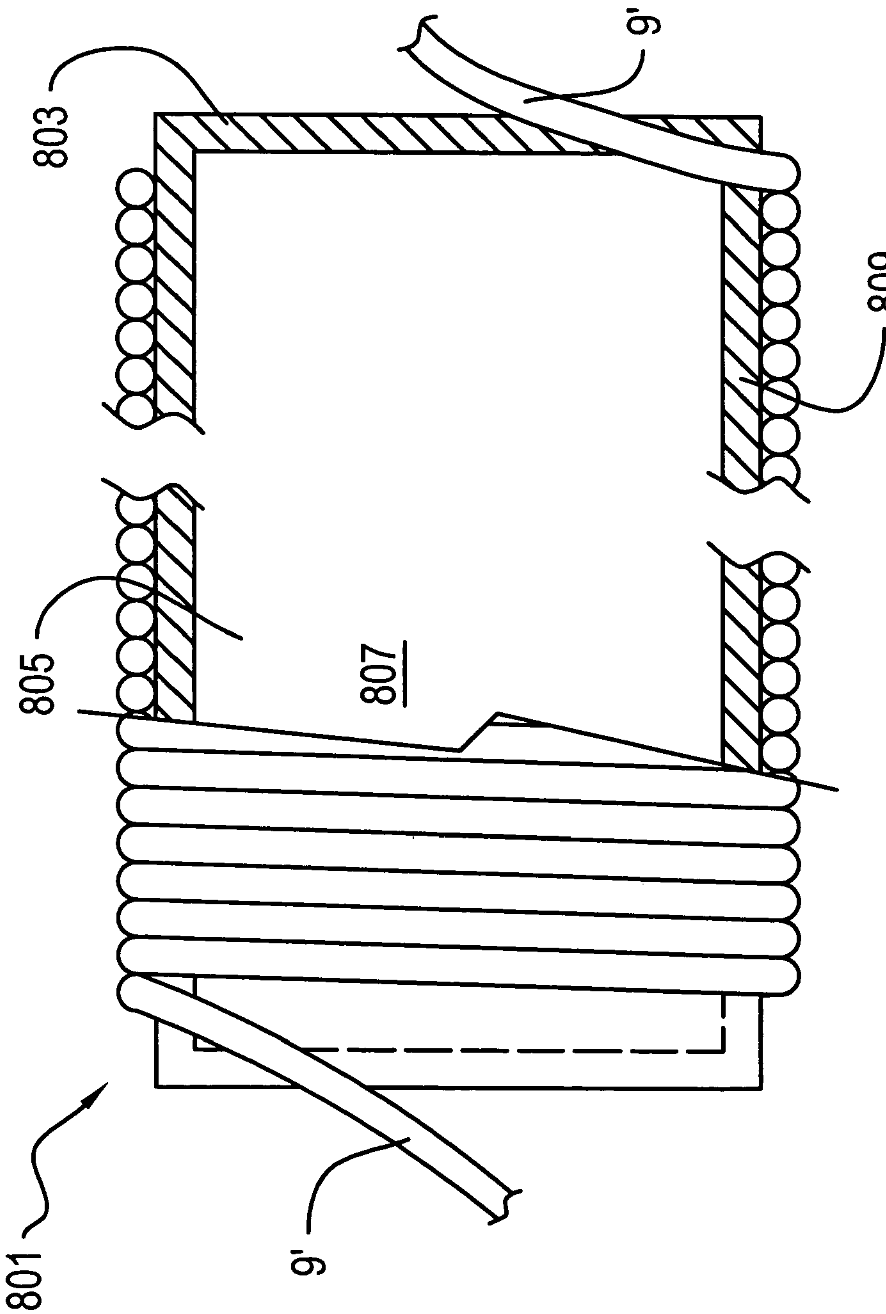


FIG. 13

NATURAL FIBER SPAN REFLECTOMETER PROVIDING A VIRTUAL SIGNAL SENSING ARRAY CAPABILITY

Applicant claims the benefit of a provisional application, No. 60/599,437 which was filed on 6 Aug. 2004, and which is entitled "Continuous Rayleigh Effect Sensor Backscattering Heterodyne Optical Sensor System" by Robert M. Payton.

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefore.

CROSS-REFERENCE TO RELATED APPLICATIONS

"Natural Fiber Span Reflectometer Providing a Spread Spectrum Virtual Sensing Array Capability" (Navy Case No 96650) filed on even date herewith in the name of Robert M. Payton, hereby incorporated herein by reference in its entirety.

"Natural Fiber Span Reflectometer Providing A Virtual Phase Signal Sensing Array Capability" (Navy Case No. 96518) filed on even date herewith in the name of Robert M. Payton, hereby incorporated herein by reference in its entirety.

"Natural Fiber Span Reflectometer Providing a Virtual Differential Signal Sensing Array Capability" (Navy Case No. 96519) filed on even date herewith in the name of Robert M. Payton, hereby incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

The present invention relates generally to the field of time-domain reflectometers. More specifically, it relates to such reflectometers which are a part of a photonic system application in which the object of the reflectometry is a span of fiber which has an interrogation signal launch end and a remote end. The invention enables the provision of a linear array of virtual sensors along the span. One particular type of application toward which the invention is directed are acoustic security alarm systems in which the span serves as a perimeter intrusion monitoring line.

(2) Description of the Prior Art

The U.S. Department of the Navy has been engaged in the development of towed acoustic arrays which are reflectometric systems in which the object of the reflectometry is a fiber span having an interrogation signal launch end and a remote end. One such development involves forming a towed array of acoustic sensors along the span by the costly process of irradiating Bragg reflective gratings into the fiber cable. These reflective gratings form the array of sensors of the reflectometry scheme of these systems. These towed arrays have a length of the order of at least 1.0 km, and the need to irradiate the fiber has resulted in the fiber spans costing hundreds of thousands of dollars each.

The Department of the Navy development activities have been further tasked to apply their creative efforts to homeland defense problems. As part of this effort there is under consideration the use of a reflectometer in which a fiber span is the object of the reflectometry. In this scheme, the fiber span provided with acoustic sensors would be used as an intrusion detector to monitor the perimeter of an area desired to be secure. The span lengths for this type of application include lengths of the order of 5 km, (links of a U.S. border protection network, oil line protection, chemical plant protection, etc.). In such perimeter monitoring applications thousands of acoustic sensors would be required along the fiber span.

The cost of manufacturing such perimeter monitoring spans employing reflective Bragg grating sensors has been an obstacle to their use in perimeter intrusion monitoring applications. Thus, there is considerable interest in the development of a reflectometer system in which a fiber span is the object of the reflectometry optic array that does not require the high cost of Bragg reflective acoustic sensors.

Previous effort in solving related problems are described by the following patents:

U.S. Pat. No. 5,194,847 issued Mar. 16, 1993 to H. Taylor and C. Lee discloses an apparatus for sensing intrusion into a predefined perimeter which comprises means for producing a coherent pulsed light, which is injected into an optical sensing fiber having a first predetermined length and positioned along the predefined perimeter. A backscattered light in response to receiving the coherent light pulses is produced and coupled into an optical receiving fiber. The backscattered light is detected by a photodetector and a signal indicative of the backscattered light is produced. An intrusion is detectable from the produced signal as indicated by a change in the backscattered light. To increase the sensitivity of the apparatus, a reference fiber and interferometer may also be employed.

U.S. Pat. No. 6,285,806 issued on Sep. 4, 2001 to A. Kersey et al., discloses an apparatus and method for measuring strain in an optical fiber using the spectral shift of Rayleigh scattered light. The interference pattern produced by an air gap reflector and backscatter radiation is measured. Using Fourier Transforms, the spectrum of any section of fiber can be extracted. Cross correlation with an unstrained measurement produces a correlation peak. The location of the correlation peak indicates the strain level in the selected portion of optical fiber.

The above patents do not show how to obtain signals representing acoustic pressure signals incident upon a fiber span (to detect perimeter intrusion) at a very large number of sensing stations without involving high manufacturing costs. Consequently, those skilled in the arts will appreciate the present invention which addresses these and other problems.

SUMMARY OF THE INVENTION

The objects of the present invention include the provision of:

(1) A time-domain reflectometer wherein an optical fiber span is the object of the reflectometry, and which provides output signals representative of acoustic pressure waves incident the span solely by virtue of the natural, or innate, properties of commercial grade optical fiber cables.

(2) The reflectometer described in object number (1), above, capable of providing acoustic wave signal sensing lengths of 5.0 km or more.

(3) The reflectometer described in object number (2), above, which facilitates the provision of a very large plurality (e.g. 5,000 or more) virtual acoustic sensors along the span.

(4) The reflectometer described in object number (1), above having a mode of operation which inherently attenuates

undesired noises due to span line discontinuities, such as reflections caused by fiber cable couplings.

(5) The reflectometer described in objects numbered (1) through

(4), above, having special utility as a perimeter intrusion monitoring line for an acoustic security alarm system.

(6) The reflectometer described in object numbered (1), above, which is capable of providing output signals in the form of a phase signal which varies linearly with the acoustic pressure wave.

(7) The reflectometer described in object numbered (3), above, which is capable of providing output signals in the form of phase differential signals across pairs of the virtual sensors.

(8) The reflectometer described in the object number (7), above, providing a capability of programmably selecting a pair, or pairs, of virtual acoustic sensors across which the phase signals are picked off, from among the plurality of virtual signals along the span.

These and other objects, features, and advantages of the present invention will become apparent from the drawings, the descriptions given herein, and the appended claims. However, it will be understood that the above listed objects and advantages of the invention are intended only as an aid in understanding aspects of the invention, and not intended to limit the invention in any way, and do not form a comprehensive list of objects, features, and advantages.

Accordingly, a time-domain reflectometer is provided for sensing and providing output signals representative of acoustic wave signals incident on the fiber span which is the object of the reflectometry, wherein the innate properties of low cost, commercially available fiber optic cables are employed to create a plurality (upwardly extending to very large numbers, e.g., 5000 and more) virtual sensors.

The present invention is implemented as follows: Time and spatial domain multiplexing and de-multiplexing of optical signals is accomplished by an electronic-delay or time of-transversal-delay coupled with modulated-retransmission of a master or reference carrier wave. Each individual optical signal occupies a unique time-delay slot or bin. A master or carrier wave is modulated with each individual optical signal and delayed by the appropriate time interval specific to a particular signal. All such signals are combined and simultaneously transmitted as a composite optical signal to a receiver where these are collected and photodetected. By correlating the photodetected composite optical signal with the master or reference carrier wave, each individual optical signal is sorted or demultiplexed into separate electronic signal channels. The continuous wave nature of the master or reference carrier wave provides more power than a pulsed optical wave and heterodyne optical reception of the invention allows a very low optical detection threshold or noise floor. The invention provides significant improvement over other systems because the optical noise floor is lowered considerably over more conventional means.

The invention applies to several applications. The invention allows audio bandwidth (tens of kilohertz bandwidth) providing time-domain reflectometry measurements of fiber optical cables or other optical mediums such as glass, air, water, etc. Other time-domain reflectometry methods do not sample the optical medium fast enough to detect tens of kilohertz bandwidth variations in the medium. The invention also relates to fiber optic sensors and optical sensors generally. A fiber optic sensor array is typically time-domain multiplexed by the time-of-transversal of an interrogation lightwave to each sensor and back to a common optical collection and detection point. The invention relates generally to both amplitude and phase type optical senor arrays. The invention is an enabling technology for a Department of Navy development known as the Rayleigh Optical Scattering and Encoding (ROSE) sensor system. The spatial separation of segmentation of a ROSE acoustic array into spatial channels is enabled by the invention.

The invention relates to acoustic security alarm systems, Naval towed arrays for sensing underwater acoustic signals, fiber optic bugging devices, and many other potential ROSE applications. The invention also relates to non-fiber optical sensors such as: laser velocimeters; lasers imagers; laser radar; laser rangers; and remote laser acoustic, strain, motion or temperature measurement devices.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the invention and many of the attendant advantages thereto will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawing, wherein like reference numerals refer to like parts and wherein:

FIG. **1** is a graphical depiction of certain underlying physical mechanisms of polarization;

FIG. **2** is a block diagram helpful in understanding the concept of launch of an interrogation signal along an optical fiber span providing a virtual array of pressure wave sensors by retrieval of backscatter from Rayleigh Optical Scatter (ROS) effects;

FIG. **3** is a block diagram of a natural fiber span time-domain reflectometer system in accordance with the present invention;

FIG. **4** is an electrical schematic of a balanced heterodyne optic detector circuit;

FIG. **5** is an electrical schematic of an alternative embodiment of a photodetector type heterodyner;

FIG. **6** is a block diagram of a programmable correlator subsystem, which enables spatial sampling of optical signals on the fiber optic span of the system of FIG. **3**, in order to provide a virtual array of acoustic wave sensors therealong;

FIG. **7** is a block diagram depiction of a set of phase demodulator circuit assemblies which receives the outputs of the programmable correlator subsystem of FIG. **6**;

FIG. **8** is a block diagram of one of the phase demodulator circuit assemblies of the set of FIG. **7**;

FIG. **9** is a block diagram disclosing details of an I & Q demodulator component in a phase demodulator circuit assembly of FIG. **8**;

FIG. **10** is a block diagram disclosing details of a digital embodiment of the phase detector component phase demodulator circuit assembly of FIG. **8**;

FIG. **11** is a block diagram disclosing details of an analog embodiment of the phase detector component phase demodulator circuit assembly of FIG. **8**;

FIG. **12** is a block diagram of a programmable routing and phase signal switching network which provides selective pairing of the outputs of the set of phase demodulators of FIG. **7** to provide differential phase signals across pairs of virtual sensors along the fiber span in accordance with the present invention; and

FIG. **13** is a diagrammatic depiction of embodiment of invention of FIG. **3** in which portions of the optical fiber span are wound around a hollow mandrel.

DESCRIPTION OF THE PREFERRED EMBODIMENT

(1) Description of Underlying Theories

a. Heterodyne Optical Detection

Optical receivers are built around photodetectors which detect optical power rather than instantaneous electric field. Typically the photodetector output current is proportional to the incident optical power. This relationship severely limits the dynamic range of an incoherent optical receiver because for every decibel of optical power lost in a receiver system two decibels of receiver output current is lost. The square law characteristics of photodetectors limits typical incoherent optical receivers (often called video detection receivers) to dynamic ranges of less than 80 dB and optical detection noise floors to greater than −80 dBm per Hertz bandwidth. As illustration, suppose an electric field $E_s(t)$ [volt/meter] immersed in a material of impedance η [Ohms] impinges upon a photodetector of responsivity $\mathfrak{R}$[ampere/watt] loaded by resistor R_1 and amplified by amplification A, then the optical power P_s by amplification A, is:

$$P_s(t) = \frac{\langle \vec{E}_s(t) \cdot \vec{E}_s(t) \rangle}{\eta} \tag{1}$$

The photodetector output current [amperes] is:

$$i(t)=\mathfrak{R}P_S(t) \tag{2}$$

The photoreceiver output [volts] is thus:

$$v(t)=AR_L i(t)=AR_L\mathfrak{R}P_S(t) \tag{3}$$

The output fades only if the optical signal power goes to zero because the vector dot product of an optical signal against itself has no polarization or phase effects. This lack of fading due to polarization or phase comes at a cost: phase information is lost and signal to noise ratios are severely impacted.

A coherent optical receiver takes advantage of the square law characteristics of photodetectors. A coherent optical receiver combines two optical beams, a signal and a local oscillator, together to form an interference. The interference between these optical waves produces a "beat" which allows the measurement of the phase difference between the signal and the local oscillator. This interference produces an amplitude, polarization, and phase sensitive receiver output. In order to consider these effects a discussion of the polarization state of plane waves is in order. A plane wave contains two orthogonal vector components which are also orthogonal to the direction of propagation of the wave. For purposes of discussion we will consider the plane wave to be oriented so that the vector components of the electromagnetic field lie in an X-Y plane and that the wave propagates in the Z direction. However, this choice of axes is completely arbitrary. In practice, the wave can be oriented in any propagation direction. In order to simplify discussions, a simple change of coordinates will make this discussion completely general.

The polarization of an electromagnetic (or optical) plane wave, p, is described by a minimum of five parameters. There are two basic ways of specifying these parameters. The first way leads to a description which is oriented towards that which is directly obtained from physical measurements.

$$\vec{E}_p(E_{px}, E_{py}, \Phi_{px}, \Phi_{py}, \omega_p, t) = \begin{bmatrix} E_{px}(t)\cos(\omega_p t + \Phi_{px}) \\ E_{py}(t)\cos(\omega_p t + \Phi_{py}) \end{bmatrix} \tag{4}$$

The second manner of describing the polarization state of a wave, p, is oriented more towards the underlying physical mechanisms of polarization. See FIG. **1**. The description is made in terms of spatial and temporal parameters:

$$\vec{E}_p(E_p, \theta_p, \psi_p, \phi_p, \omega_p, t) = E_p(t)\begin{bmatrix} \cos(\theta_p) & \sin(\theta_p) \\ -\sin(\theta_p) & \cos(\theta_p) \end{bmatrix}\begin{bmatrix} \cos(\psi_p) & 0 \\ 0 & \sin(\psi_p) \end{bmatrix}\begin{bmatrix} \cos(\omega_p t + \phi_p) \\ \sin(\omega_p t + \phi_p) \end{bmatrix} \tag{5}$$

Alternatively, dropping the full variable list in the parentheses and expanding:

$$\vec{E}_p(t) = E_p(t)\begin{bmatrix} \cos(\theta_p) & \sin(\theta_p) \\ -\sin(\theta_p) & \cos(\theta_p) \end{bmatrix}\begin{bmatrix} \cos(\psi_p) & 0 \\ 0 & \sin(\psi_p) \end{bmatrix}\begin{bmatrix} \cos(\phi_p) & -\sin(\phi_p) \\ \sin(\phi_p) & \cos(\phi_p) \end{bmatrix}\begin{bmatrix} \cos(\omega_p t) \\ \sin(\omega_p t) \end{bmatrix} \tag{6}$$

If E_p is constant, the electrical power of this wave can be shown to be constant and equal to:

$$P_p(t) = \frac{\langle \vec{E}_p(t) \cdot \vec{E}_p(t) \rangle}{\eta} = \frac{E_p^2}{2\eta} \tag{7}$$

When two waves, S (signal) and L (local oscillator), interfere at the input of a photoreceiver, the output is:

$$v_{out}(t) = AR_L i(t) = AR_L\mathfrak{R}\frac{\langle \vec{E}_s(t) \cdot \vec{E}_s(t) + \vec{E}_L(t) \cdot \vec{E}_L(t) + 2\vec{E}_L(t) \cdot \vec{E}_s(t) \rangle}{\eta} \tag{8}$$

$$v_{out}(t) = v_L(t) + v_s(t) + v_{LS}(t) = AR_L\mathfrak{R}(P_L(t) + P_s(t) + P_{LS}(t))$$

If the optical power of the local oscillator and signal lightwaves remain constant, a constant photocurrent develops for the self-interference terms (P_S and P_L). However, if either the local oscillator or the signal lightwaves have any temporal variation in polarization or phase, the cross interference term (P_{LS}) will be time dependent even if the power of each lightwave remains constant. Solving for the cross interference term, we obtain:

$$v_{LS}(t) = \frac{AR_L\Re}{\eta} E_L(t)E_s(t)[\cos(\Delta\theta)\cos(\Delta\psi)\cos(\Delta\omega t + \Delta\phi) + \sin(\Delta\theta)\sin(2\overline{\psi})\sin(\Delta\omega t + \Delta\phi)] \tag{9}$$

$$v_{LS}(t) = 2AR_L\Re\sqrt{P_L(t)P_s(t)}\,[\cos(\Delta\theta)\cos(\Delta\psi)\cos(\Delta\omega t + \Delta\phi) + \sin(\Delta\theta)\sin(2\overline{\psi})\sin(\Delta\omega t + \Delta\theta)]$$

Where the following definitions are made:

$$\Delta\theta=\theta_S-\theta_L$$

$$\Delta\psi=\psi_S-\psi_L$$

$$2\overline{\psi}=\psi_S+\psi_L$$

$$\Delta\omega=\omega_S-\omega_L$$

$$\Delta\phi=\phi_S-\phi_L \tag{10}$$

The optical cross-interference portion of the receiver output will fade due to polarization even if the local oscillator and the signal lightwaves both do not have zero optical powers. This condition will occur if:

$$O=\cos(\Delta\sigma)\cos(\Delta\psi)\cos(\Delta\omega t+\Delta\phi)=\sin(\Delta\sigma)\sin(2\overline{\psi})\sin(\Delta\omega t+\Delta\Phi) \tag{11}$$

Also, equivalently when the condition will occur:

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} \cos(\Delta\theta)\cos(\Delta\psi)\cos(\Delta\omega t + \Delta\phi) \\ \sin(\Delta\theta)\sin(2\overline{\psi})\sin(\Delta\omega t + \Delta\phi) \end{bmatrix} \tag{12}$$

When heterodyne optical detection is employed (Δω is non-zero, the local oscillator has a different frequency from the signal), the conditions for a fade are shown in Table 1. When homodyne detection is employed (Δω is zero), both phase and polarization fading occur. The conditions for a homodyne fade are shown in Table 2. Heterodyne detection is therefore seen to be superior to homodyne because the probability of a fade is fully one half as likely.

TABLE 1

Heterodyne Fading Conditions

Type of Fade (k is an integer	Required Simultaneous Conditions for a Fade to Occur	
Orthogonal Rotation and Opposite Ellipticity	$\Delta\delta = (2k + 1)\pi/2$	$\psi_S + \psi_L = 0$
Orthogonal Rotation and Equal Circular Ellipticity	$\Delta\delta = (2k + 1)\pi/2$	$\psi_S + \psi_L \pm \pi$
Equal Rotation and Orthogonal Ellipticity	$\Delta\delta = 0$	$\Delta\psi = \pm\pi/2$
Opposite Rotation and Orthogonal Ellipticity	$\Delta\delta = \pm\pi$	$\Delta\psi = \pm\pi/2$

TABLE 2

Homodyne Fading Conditions

Type of Fade (k and m are integers)	Required Simultaneous Conditions for a Fade to Occur	
Orthogonal Rotation and Opposite Ellipticity	$\Delta\delta = (2k + 1)\pi/2$	$\psi_S + \psi_L = 0$
Orthogonal Rotation and Equal Circular Ellipticity	$\Delta\delta = (2k + 1)\pi/2$	$\psi_S + \psi_L \pm \pi$
Equal or Opposite Rotation and Orthogonal Ellipticity	$\Delta\delta = k\pi$	$\Delta\psi = \pm\pi/2$
Orthogonal Rotational and Equal or Opposite Phase	$\Delta\delta = (2k + 1)\pi/2$	$\Delta\phi = m\pi$

Given the conditions for and the functional relation of a fade, the question now arises as to how a fade can be prevented. Since the signal is being measured, no a priori knowledge is assumed and therefore E_S, σ_S, Ψ_S, Φ_S are all probably unknown quantities. If fading is prevented, then no loss of information occurs and determination of these four parameters is possible. In order to decode the optical receiver output into these parameters, at least four independent measurements must be made to uniquely determine these four independent variables. However, if the interfering optical beam (or beams) of the local oscillator are unknown, then additional independent measurements must be made (four additional measurements for each unknown beam) to determine the E_L, σ_L, Ψ_L, or Φ_L for each optical beam of the local oscillator. The cross-reference output of the photoreceiver, $v_{LS}(t)$, offers the only means by which to measure these parameters. If the parameters cannot be determined from this output, then an optical fade cannot be ruled out.

We shall now examine the information which can be gleaned from this output. Define the following functions.

$$v_I(E_L, E_S, \Delta\theta, \Delta\psi) = \frac{AR_L\Re}{2\eta}E_L(t)E_S(t)\cos(\Delta\theta)\cos(\Delta\psi) = AR_L\Re\sqrt{P_L(t)P_S(t)}\cos(\Delta\theta)\cos(\Delta\psi) \tag{13}$$

$$v_Q(E_L, E_S, \Delta\theta, 2\overline{\psi}) = \frac{AR_L\Re}{2\eta}E_L(t)E_S(t)\sin(\Delta\theta)\sin(2\overline{\psi}) = AR_L\Re\sqrt{P_L(t)P_S(t)}\sin(\Delta\theta)\sin(2\overline{\psi})$$

In the homodyne case (Δω is zero), we obtain the following output:

$$v_{LS}(t) = 2AR_L\Re\sqrt{P_L(t)P_S(t)}\,(\cos(\Delta\theta)\cos(\Delta\psi)\cos(\Delta\phi) + \sin(\Delta\theta)\sin(2\overline{\psi})\sin(\Delta\phi)) \tag{14}$$

$$v_{LS}(t) = 2v_I(E_L, E_S, \Delta\theta, \Delta\psi)\cos(\Delta\phi) + 2v_Q(E_L, E_S, \Delta\theta, 2\overline{\psi})\sin(\Delta\phi)$$

The homodyne output only allows the measurement of one quantity. The output provides only one independent measurement (one equation) whereas a minimum of four are required. In the heterodyne case ($\Delta\omega$ is non-zero), the output is:

$$v_{LS}(t) = 2AR_L\Re\sqrt{P_L(t)P_S(t)}\,(\cos(\Delta\theta)\cos(\Delta\psi)\cos(\Delta\omega t + \Delta\phi) + \sin(\Delta\theta)\sin(2\overline{\psi})\sin(\Delta\omega t + \Delta\phi)) \quad (15)$$

$$v_{LS}(t) = \frac{AR_L\Re}{\eta}E_L(t)E_S(t)(\cos(\Delta\theta)\cos(\Delta\psi)\cos(\Delta\omega t + \Delta\phi) + \sin(\Delta\theta)\sin(2\overline{\psi})\sin(\Delta\omega t + \Delta\phi))$$

$$v_{LS}(t) = 2v_I(E_L, E_S, \Delta\theta, \Delta\psi)\cos(\Delta\omega t + \Delta\phi) + 2v_Q(E_L, E_S, \Delta\theta, 2\overline{\psi})\sin(\Delta\omega t + \Delta\phi)$$

Since sine and cosine waves are orthogonal, the heterodyne receiver provides two independent measurements by mixing down to baseband the $\Delta\omega$ radian frequency components. Thus, two outputs are obtained:

$$V_I(t) = \langle v_{LS}(t)\cos(\Delta\omega t)\rangle = v_I(E_L(t), E_S(t), \Delta\theta(t), \Delta\psi(t))\cos(\Delta\phi(t)) \quad (16)$$

$$V_Q(t) = \langle v_{LS}(t)\sin(\Delta\omega t)\rangle = v_Q(E_L(t), E_S(t), \Delta\theta(t), 2\overline{\psi}(t))\sin(\Delta\phi(t))$$

b. Correlation or Time-Delay Multiplexing

In many optical sensor applications, the lightwave signal heterodyne-detected by the photodetector system is a composite optical signal formed from the superposition of many individual optical signals. When the receiver lightwave is generated by backscatter, the composite optical signal is the superposition of individual light signals generated by a continuum of reflections of an interrogation light source. The temporal and spatial characteristics of each reflector or reflective region creates a modulation of the interrogation light source. The time-delay, amplitude, polarization and phase states control the backscattered-modulation of these individual optical signals arriving at the photodetector with a unique time-delay interval can be separated into channels which sort the optical signals into time-delay slots or bins. Depending upon how the signals are generated, these channels can represent spatial regions in space or time-delay slots of a time-domain reflectometer mechanism.

Let an interrogation lightwave source be generated by modulating the amplitude, phase or polarization of a coherent lightwave with a time-structured correlation code, c(t). The correlation code, c(t) can be a series of pulses, chirps, binary sequences or any other type of code which provides the required correlation characteristics. If the lightwave source is:

$$E_{SS}(t)=E_{SS}\cos(\omega_S t) \quad (17)$$

Then an amplitude modulated interrogation source is:

$$E_i(t)=\mu_A c(t)E_{SS}\cos(\omega_S t) \quad (18)$$

Alternatively, a phase modulated interrogation source is:

$$E_i(t)=E_{SS}\cos(\omega_S t+\mu_p c(t)). \quad (19)$$

If c(t) is chosen to be temporally structured properly, then:

$$R_i(\tau) = \langle E_i(t)E_i(t+\tau)\rangle \approx \begin{cases} \frac{E_{SS}^2}{2};\ \tau \approx 0 \\ 0;\ \text{otherwise} \end{cases} \quad (20)$$

c(t) must be chosen so that an a priori decoding/demultiplexing function, d(t), exists such that:

$$b(t,\tau) = \langle d(t)E_i(t+\tau)\rangle \approx \begin{cases} \xi E_{SS}\cos(\Delta\omega t + \phi);\ \tau \approx 0 \\ 0;\ \text{otherwise} \end{cases} \quad (21)$$

For instance, suppose the interrogation wave is:

$$E_i(t)=\mu_A c(t)E_{ss}\cos(\omega_S t) \quad (22)$$

and:

$$R_c(\tau) = \langle c(t)c(t-\tau)\rangle \approx \begin{cases} 1;\ \tau \approx 0 \\ 0;\ \tau \neq 0 \end{cases} \quad (23)$$

then a valid decoding and temporal and spatial domains demultiplexing function is:

$$d(t) = \mu_d C(t)E_L\cos((\Delta\omega + \omega_S)t + \phi) \quad (24)$$

$$b(t,\tau) = \langle d(t-\tau)E_i(t)\rangle = \begin{cases} \frac{\mu_d\mu_A E_{SS}E_L}{2}\cos(\Delta\omega(t-\tau) + \phi - \omega_S\tau);\ \tau \approx 0 \\ 0;\ \text{otherwise} \end{cases}$$

Therefore, delaying the correlation decoding/demultiplexing function d(t) allows demultiplexing of delay multiplexed signals identifiable by speed of propagation and distance of flyback travel. Suppose an optical wave is formed a summation of delayed signals modulated onto the interrogation wave $E_i(t)$, then the received wave, $E_b(t)$, is:

$$E_b(t) = \sum_{n=1}^{N} A_n(t-\tau_n)\mu_A c(t-\tau_n)E_{SS}\cos(\omega_S(t-\tau_n)+\Phi_n(t-\tau_n)) \quad (25)$$

Then multiplying by the decoding/demultiplexing function, $d(t-\tau_m)$, we obtain:

$$d(t) = \mu_d c(t)E_L\cos((\Delta\omega+\omega_S)t+\phi) \quad (26)$$

$$b(t,\tau_m) = \langle d(t-\tau_m)E_b(t)\rangle$$

$$b(t,\tau_m) \approx \frac{\mu_d\mu_A E_{SS}E_L}{2}A_m(t-\tau_m)\cos(\Delta\omega(t-\tau_m)+\phi-\omega_S\tau_m+\Phi_m(t-\tau_m)).$$

Because τ_n is unique, the amplitude signal $A_m(t-\tau_m)$ and the phase signal $\Phi_m(t-\tau_m)$ are both extracted from $E_b(t)$ by multiplying by the decoding/demultiplexing function, $d(t-_m)$. The technique is applicable to a wide variety of other optical signal multiplexing applications. Specifically, the technique can be used to spatially separate optical signals arriving from a temporally varying time-domain reflectometer optical backscatter process from an array of fiber optic acoustic sensors.

(2) Description and Operation of the Rayleigh Optical Scattering and Encoding (ROSE) System

a. ROSE Optical Phase Sensor Interrogation Enables Sensor Subsystem

In order to more fully describe the capabilities and new features of the invention, the application of the invention to a subsystem **1**, FIG. **2**, of ROSE which launches an interrogation signal onto fiber span **9** and retrieves lightwave back propagation from a continuum of locations along the span. Back propagation mechanisms may include Rayleigh Optical Scattering (ROS) and other effects generated within the optical fiber. Rayleigh Optical Scattering (ROS) in an optical fiber backscatters light incident upon the fiber. The incident light transverses down the optical fiber to the scattering point/region. At the scattering region the incident light is backscattered back up the optical fiber. As the light transverses the round trip optical path (i.e., distance of flyback travel) any disturbance of the fiber which increase or decrease the optical path length will cause the phase of the incident and backscattered light to be modulated. Suppose a pressure is applied to the optical fiber. The pressure elongates the path length of the light transversing the region.

Refer to FIG. **2**. for the following discussion. In the FIGS. like parts correspond to like numbers. Let p(t,z) be pressure applied to the outside of the optical fiber at time, t, and at point or length, z, along the fiber axis. Then if an interrogation optical wave, $E_i(t)$, generated by laser **3**, passed through optical coupler **4** and modulated by optical modulator **5** is applied to optical coupler **7**, this results in the following output interrogation wave, $E_i(t)$, being transmitted down the fiber **9**:

$$E_i(t)=\mu_A c(t)E_{ss}\cos(\omega_S t). \quad (27)$$

The backscattered wave, $E_b(t)$, arriving back at an optical coupler **7** from ROSE fiber optic array **9** passes into optical path **11**. The backscattered light which arrives at optical path **11** is the summation of all light backscattered from a continuum of locations along the length of the ROSE fiber optic span **9**. As will later herein be described in detail, fiber **9** has a longitudinal strain component enhancing coating **12**. If r(z) is the reflection density at point or length z along the fiber and CL is the optical wave speed, then the backscattered light after a pressure p(t,z) is applied to fiber is represented mathematically as:

$$E_b(t) = \int_0^\infty r(\hat{z}(t,z))\mu_A c\left(t-\frac{2\hat{z}(t,z)}{c_L}\right)E_{SS}\cos\left(\omega_S\left(t-\frac{2\hat{z}(t,z)}{c_L}\right)\right)dz \quad (28)$$

where:

$$\hat{z}(t,z) = z+\mu_L\int_0^z p(t,x)\,dx. \quad (29)$$

If the distributed reflection, r(z) is essentially independent of the applied pressure, p(t,z) then the backscatter is:

$$E_b(t) = \int_0^\infty r(z)\mu_A c\left(t-\frac{2\hat{z}(t,z)}{c_L}\right)E_{SS}\cos\left(\omega_S\left(t-\frac{2\hat{z}(t,z)}{c_L}\right)\right)dz. \quad (30)$$

Since optical path length change caused by the applied pressure, p(t,z) is usually extremely small (on the order of 10^{-6} to 10^1 times an optical wavelength), the backscattered light from each z distance down the fiber arrives at the optical path **11** with a transversal delay, $\tau(t,z)$, equal to:

$$\tau(t,z) \approx \frac{2z}{c_L}. \quad (31)$$

Therefore, to receive the signal S_1 backscattered from the fiber region at length-down-the-fiber $z=L_1$, the correlational multiplexing characteristic of the transmitted interrogation light can be utilized. Multiplication of the total backscattered optical signal by the correlation decoding/demultiplexing function, $d(t-\tau(t,z_1))$, produces an output which contains the signal, S_1, backscattered from a distance L_1 down the fiber and rejects signals originating from other fiber regions, such as S_2, S_n and etc. Representing this process mathematically, the resulting channel output, $B(t, L_1)$ is obtained as follows:

$$b(t,\tau_1)=\langle d(t-\tau_1)E_b(t)\rangle=\left\langle d\left(t-\frac{2L_1}{c_L}\right)E_b(t)\right\rangle=B(t,L_i) \tag{32}$$

$$d\left(t-\frac{2L_1}{c_L}\right)=\mu_d c\left(t-\frac{2L_1}{c_L}\right)E_L\cos\left((\Delta\omega+\omega_s)\left(t-\frac{2L_1}{c_L}\right)+\phi\right)$$

$$E_b(t)=\int_0^\infty r(z)\mu_A c\left(t-\frac{2z}{c_L}\right)E_{SS}\cos\left(\omega_s\left(t-\frac{2\hat{z}(t,z)}{c_L}\right)\right)dz$$

$$\Phi(z,L_1)=\phi-\frac{2(\Delta\omega+\omega_s)L_i}{c_L}+\Delta\omega\frac{2z}{c_L}$$

$$B(t,L_1)=\mu_d\mu_A E_L E_{SS}\int_0^\infty r(z)R_c\left(\frac{2(z-L_1)}{c_L}\right)\cos\left(\Delta\omega t+\Phi(z,L_1)+\frac{2\mu_L\omega_S}{c_L}\int_0^z p(t,x)\,dx\right)dz \tag{33}$$

$$\Delta\Phi(t,z)=\Phi(z,L_1)+\frac{2\mu_L\omega_S}{c_L}\cdot\int_0^z p(t,x)\,dx$$

$$B(t,L_1)=V_E\int_0^\infty r(z)R_c\left(\frac{2(z-L_1)}{c_L}\right)\cos(\Delta\omega t+\Delta\Phi(t,z))\,dz$$

$$B(t,L_1)\approx V_E r_{L_1}\cos\left(\Delta\omega t+\Phi_{L_1}+\frac{2\mu_L\omega_S}{c_L}\cdot\int_0^{L_1}p(t,x)\,dx\right)$$

Because of the correlation properties of the interrogation light, the autocorrelation function $R_c(\tau)$ is very small at all spatial locations except those in the vicinity of $z=L_1$. Therefore, all signals originating anywhere else are rejected. Furthermore, the phase of the channel output at location L_1 will be the summation or integration of all pressure changes along the bi-directional transversal path. This unusual phenomenon has been demonstrated with experimental hardware.

Once the correlation process isolates the optical signal originating from a spatial region, the signal must be phase demodulated to extract the pressure information. The signal is I (in phase) and Q (quadrature phase) demodulated is:

$$B_1(t,L_1)=\langle B(t,L_1)\cos(\Delta\omega t)\rangle \tag{34}$$

$$B_1(t,L_1)\approx V_E r_{L_1}\cos\left(\Phi_{L_1}+\frac{2\mu_L\omega_S}{c_L}\cdot\int_0^{L_1}p(t,x)\,dx\right)=V_1\cos(\Phi_1)$$

$$B_Q(t,L_1)=\langle B(t,L_1)\sin(\Delta\omega t)\rangle$$

$$B_Q(t,L_1)\approx -V_E r_{L_1}\sin\left(\Phi_{L_1}+\frac{2\mu_L\omega_S}{c_L}\cdot\int_0^{L_1}p(t,x)\,dx\right)=-V_1\sin(\Phi_1).$$

Then I & Q, or cosine phase and sine phase outputs are converted into either phase rate or phase outputs with simple analog or digital hardware. The phase, so demodulated, allows the inference of information about the acoustic pressure down the fiber to the measurement point.

Once the I & Q outputs are generated, the temporal phase state of $B(t, L_1)$ can be determined by one of several types of phase demodulation processes. The phase state of the region of L_1 spatial delay is therefore:

$$\Phi_1=\Phi_{L_1}+\frac{2\mu_L\omega_S}{c_L}\cdot\int_0^{L_1}P(t,x)\,dx. \tag{35}$$

Likewise, the plurality (which may be a large number, e.g., 5000) of optical signals arising with spatial delays, such as the propagation time for flyback travel to L_2 or L_n, can be correlated out of the backscattered signal $E_b(t)$. These are:

$$B(t,L_2)\approx V_E r_{L_2}\cos\left(\Delta\omega t+\Phi_{L_2}+\frac{2\mu_L\omega_S}{c_L}\cdot\int_0^{L_2}p(t,x)\,dx\right) \tag{36}$$

$$B(t,L_n)\approx V_E r_{L_n}\cos\left(\Delta\omega t+\Phi_{L_n}+\frac{2\mu_L\omega_S}{c_L}\cdot\int_0^{L_n}p(t,x)\,dx\right)$$

With corresponding phase signals of:

$$\Phi_2=\Phi_{L_2}+\frac{2\mu_L\omega_S}{c_L}\cdot\int_0^{L_2}p(t,x)\,dx \tag{37}$$

$$\Phi_n=\Phi_{L_n}+\frac{2\mu_L\omega_S}{c_L}\cdot\int_0^{L_n}p(t,x)\,dx.$$

The phase signals, obtained by phase demodulation of each $B(t,L_m)$, represent a pressure field $p(t,z)$ which is integrated along the length, z, of the fiber. Therefore, rather than directly measure $p(t,z)$ the sensor provides all of the accumulated pressure effects down the fiber to the measurement point, L_m(where m is integer corresponding to the measurement point). In sensor arrays, it is usually desired to detect the pressure over a specific measurement region. If two optical signals S_j and S_k are received from measurement lengths L_j and L_k, the corresponding demodulated phases Φ_j and Φ_k are:

$$\Phi_j=\Phi_{L_j}+\frac{2\mu_L\omega_S}{c_L}\cdot\int_0^{L_j}p(t,x)\,dx \tag{38}$$

$$\Phi_k=\Phi_{L_k}+\frac{2\mu_L\omega_S}{c_L}\cdot\int_0^{L_k}p(t,x)\,dx.$$

A sensor between the lengths down the fiber of L_j and L_k ($L_k>L_j$) is formed by subtracting the two phases:

$$\Phi_k-\Phi_j=\Delta\Phi_{kj}=\left(\Phi_{L_k}+\frac{2\mu_L\omega_S}{c_L}\cdot\int_0^{L_k}p(t,x)\,dx\right)-\left(\Phi_{L_j}+\frac{2\mu_L\omega_S}{c_L}\cdot\int_0^{L_j}p(t,x)\,dx\right) \tag{39}$$

$$\Delta\Phi_{kj}=\Phi_{L_k}-\Phi_{L_j}+\frac{2\mu_L\omega_S}{c_L}\cdot\left(\int_0^{L_k}p(t,x)\,dx-\int_0^{L_k}p(t,x)\,dx\right)$$

-continued

$$\Delta\Phi_{kj} = \Phi_{L_k} - \Phi_{L_j} + \frac{2\mu_L\omega_S}{c_L} \cdot \int_{L_j}^{L_k} p(t, x) dx$$

$$\Delta\Phi_{kj} = \Delta\Phi_{L_kL_j} + \frac{2\mu_L\omega_S}{c_L} \cdot \int_{L_j}^{L_k} p(t, x) dx.$$

The resulting sensor is of length $\Delta L = L_k - L_j$ with a center position of $(L_k + L_j)/2$. The differencing of phase signals Φ_j and Φ_k into a new phase signal $\Delta\Phi_{kj}$, allows a virtual sensor of arbitrary position and length to be formed. The resulting spatially differential sensor also adds the advantage of minimizing other effects such as lead-in fiber strum or vibration which create unwanted phase signals.

The above phenomena illustrates that when the interrogation light is properly encoded, a ROSE (Rayleigh Optical Scattering and Encoding) sensor system is enabled. The subject invention therefore enables the ROSE concept. The subject invention enables spatial discrimination of the optical backscatter effects in a ROSE sensor. The spatial differencing technique rejects unwanted common mode signals inadvertently introduced in fiber leads down to the sensor region. The invention also applies in a similar manner to more conventional fiber optic acoustic sensor arrays (i.e., those having Bragg reflective grating sensors) or to non-fiber optic remote optical sensors which detect phase.

b. Pointwise Signal Delay Multiplexing

The invention also applies to point-wise non-distributed sensors or artificially generated multiplexing by electronics means. The interrogation lightwave can be intercepted and retransmitted back to the receiver with an artificial, electronically generated delay, as a means of delay/correlation multiplexing many channels.

(3) Description of a Fiber System Implementation

The invention can be realized with bulk optical, fiber optical or integrated optical components. For simplicity, a fiber optic implementation will be presented. However, the fiber optic embodiment is being presented without intent of limitation. The teachings of the invention can be used to implement a reflectometer system in accordance with the present invention using these and other instrumentalities providing a light path that has the innate property of producing back propagation of portions of an interrogation signal at a continuum of locations along the length of the propagation path therethrough.

a. Optical Transmitter and Time-Delay Multiplexing Process.

FIG. **3** is an illustrative block diagram implemention of the Rayleigh optical scattering and encoding (ROSE) sensor system **2**. Like parts correspond to like numbers. A lightwave from transmitter laser, **3**, is propagated through optical coupler or beamsplitter, **4**. The smaller portion of the transmitter laser power split off by optical coupler, **4**, is passed by optical path, **39**, to the phase locking means optical receiver **35**. The larger portion of the transmitter laser light power is split by optical coupler, **4**, and propagated to optical modulator, **5**. The optical modulator, **5**, modulates the laser light passing from optical coupler, **4**, with correlation code, c(t), as electronically generated in master correlation code generator, **53**, and amplified by amplifier, **49**. The correlation code, c(t), is modulated onto the laser light in optical modulator, **5**. This modulated light comprises the optical interrogation lightwave, $E_i(t)$. The optical modulator, **5**, may modulate the amplitude, polarization or phase of the laser light subject to the teachings of the invention. The interrogation lightwave is propagated from optical modulator, **5**, to optical coupler, beamsplitter or circulator, **7**. The interrogation lightwave passes through the optical coupler, **7**, into optical fiber or other light propagation medium, **9**. Hereinafter, "down", indicates a transversal on the optical path, **9**, away from coupler, **7**; "up" indicates a transversal on the optical path **9** toward the optical coupler, beamsplitter or circulator, **7**. The interrogation lightwave which transverses down the optical fiber or medium **9** is modulated and is backscattered or returned by other means with equivalent optical path lengths (equivalent to a time delay), L_1, L_2 . . . L_n corresponding to sensors or multiplexed channels S_1, S_2 . . . . S_n. The returned interrogation lightwave is a composite optical signal modulated by signals due to the S_1 through S_n modulating and time-domain multiplexing actions.

More particularly, the propagation of the optical spread-spectrum interrogation signal down the continuous full span of the optical fiber span, signal launch end to remote end, causes a back-propagating composite optical signal, which is the linear summation, or integration spatially, of all of the individual, continuous, or continuum of back-reflections along the span of the optical fiber.

One component of this composite signal is comprised of the naturally occurring continuum of optical back reflections (including Rayleigh optical scattering ((ROS)) effects) of the optical spread spectrum carrier signal that is formed by modulating the primary carrier signal by the spectrum spreading signals. Another component is comprised of the artificially occurring optical back reflections, either-point wise reflections or distributed reflections, of the optical spread spectrum carrier signal that is formed due to propagation discontinuities as the result of presence of a fiber cable coupler in span **9**. Still another component comprised of the continuum of modulations at locations along the span of the reflected signals due to longitudinal components of optical path length change, causing a delay in the reflected signal, experienced by the fiber optical span along its length.

Such optical path length change or delay may be caused by a variety of possible sources including acoustic pressure waves incident to the fiber, electromagnetic fields coupled to the fiber, mechanical strain or pressure on the fiber, thermal strain or pressure induced in the fiber, or other means of causing change in the optical path length. Use of the acoustic pressure waves mode of changing path length in perimeter intrusion monitoring systems is the principle embodiment illustrated herein. In this use, optical fiber span **9** is employed to provide an array of virtual geophones buried at a range of depths beneath the surface of the ground of about between six (6) inches and one (1) foot, to sense motion of an object on the surface of the ground. The acoustic pressure wave sensing mode is also useful to sense seismic signals, as for example as linear arrays inserted into casing structures of an existing oil wells. Predetermined artificial pressure wave producing shocks are imparted into the ground, and the responses from the sensor are used to locate secondary oil deposits. The acoustic pressure wave sensing mode is further useful for employing span **9** as an array of virtual hydrophones, with the media which couples the signals to the hydrophones at least in part being the body of water in which the array is immersed. Such hydrophone arrays find use as naval undersea warfare towed arrays, or towed geophysical exploration arrays. In the latter the arrays respond to artificially produced shocks of predetermined character and location induced in the body of water, and the response of the array to bottom return signals are used to locate ocean bottom geophysical feature indicating likely presence of an oil deposit. Yet further, a sensing position on a fiber span **9** could be used to receive as an input microphonic signals suitably imparted to the region of the sensing position. The electromagnetic field sensing mode of fiber span **9** could be used for monitoring electronic signals along a telecommunication cable's span to localize malfunctions. Responses of fiber span **9** to mechanical, pressure or thermal strains can be used in systems for monitoring such strains.

The composite lightwave propagates up the optical fiber or medium **9**, passes through optical coupler, beamsplitter or circulator, **7**, to optical pathway, **11**. Optical pathway, **11**, passes the backscattered, time-delay multiplexed, composite lightwave, $E_b(t)$, to the optical receiver, **15**.

Preferably, fiber **9** is of the relatively low cost, conventional single-mode or multimode, fiber cable types.

Further it is preferable that fiber **9** have extruded thereon a coating **12** of a material which enhances the longitudinal strain which the fiber undergoes from a given radially, or generally laterally, applied pressure wave strain. Materials which provide such enhancement include extrudable thermoplastic polymers (TPU's) or extrudable thermoplastic elastomers (TPE's) which exhibit a combination of a low Young's modules (E) and a low Poisson's ratio (σ). The Poisson's ration is preferably below 0.5, which is the Poisson's ratio of natural rubber. Examples of such materials include: (i) low density polyethylene, having characteristic $E=1.31$ dynes/$cm^2 \times 10^{-10}$ and $\sigma=0.445$; and (ii) polystyrene, $E=3.78$ dynes/cm^2 and $\sigma=0.35$ (values as reported in the paper, R. Hughes and J. Javzynski, "Static Pressure Sensitivity Amplification in Interferometric Fiber-Optic Hydrophones," Applied Optical/Vol. 19/No. 1/1 Jan. 1980).

An alternate embodiment of fiber **9**, albeit involving significantly greater cost per unit length of the fiber, is to provide fiber in the more expensive form of a polarization preserving or single polarization, optical fiber. The polarization preserving fiber of this type holds the backscattering light in a narrow range of polarization states so that a substantially single RF signal **21** enters a single set **23** of correlators, reducing the complexity of the system. However, in cases involving long surveillance lines this alternative embodiment becomes expensive in cost of fiber.

The correlation code generator **53** creates a signal, c(t), that has a broad bandwidth. The broadband nature of the correlation code is required to obtain the desired properties in the signals autocorrelation function. The calculation and definition of the autocorrelation function of any general signal is well known and defined in signal processing literature. The correlation code signal, c(t), is so structured that its autocorrelation function is highly peaked at zero delay, and is very small away from zero delay. This criterion is well known to those of skill in the art and is the essence of why the correlation code has a broad bandwidth. Any signal that has the desired autocorrelation function properties can be used as the correlation code in the invention. There are many reasons for choosing one correlation code over another: ease of creation; autocorrelation properties; cost of creation hardware; cost of correlation hardware; and effectiveness in producing spread spectrum signal effects. According to the teaching of the invention, the correlation code for the invention can be a binary sequence with a desired transorthogonal autocorrelation property (sometimes called a pseudonoise sequence), a pseudorandom number (PRN) sequence with the such desired autocorrelation property, chirps, or other types of signals which provide correlations code having predicable non-repetitive behavior. The foregoing list of types of sequence signals which may be employed to modulate the carrier lightwave signal includes both "binary pseudonoise sequences" and "pseudorandom number (PRN) sequences." For purposes of construction of this specification and the appended claims, these terms are employed as they are defined under the listings "Pseudonoise (PN) sequence (communication satellite)" and "Pseudorandom number sequence" at pages 747 and 748 of the "IEEE Standard Dictionary of Electrical and Electronic Terms" (Fourth Edition), which listings are hereby incorporated herein by reference. Further for purposes of construction of this specification and the appended claims, it is deemed that "binary pseudonoise sequence" is generic and "pseudorandom number sequence" is a species thereof. Still further for purposes of construction of this specification and its appended claims, both terms are deemed to include analog signal forms of sequences as well as digital signal forms.

It is to be appreciated that in addition to its correlation encoding function, master correlating code generator **53** is a source of a spectrum-spreading signal comprised of a spectrum-spreading signal which produces an autocorrelation that is well behaved. It has one dominate maxima at zero correlation delay, and its spectrum is large enough to provide sampling of the said optical fiber spatially along the length of the fiber **9** with a resolution commensurate with a sub-length ΔZ of fiber span **9**. These characteristics enable segmentation of an optical fiber **9** of span length L into n segments in accordance with a relationship

$$L<\Delta Z\cdot n. \tag{40}$$

In this relationship ΔZ is a segment length of the fiber span whose length is one-half the distance traveled by light propagating through one zero delay temporal time span of the autocorrelation maxima, ΔT, such that C_L is the speed of light in the said optical fiber and ΔT is approximately equal to the reciprocal of the spread signal optical bandwidth.

An illustrative embodiment of generator **53** is a shift register type pseudorandom number code generator, having n bits, wherein a code is generated that satisfies said resolution sublength and segment length relationship by choosing an appropriate combination of the number of its bits and the clock time.

The temporal length of the code sequence which is reiteratively produced by generator **53** may be either less than the time period for propagation of a lightwave to the remote end of span and propagation back of a backscattering (i.e. distance of flyback travel), or greater than this time period. It cannot be equal to this period.

The predetermined timing base employed by the source of the spectrum spreading signals, which determines the length of ΔZ segment is so chosen to provide a positive enhancement to the ratio of the power of back propagating Rayleigh scattering effect P_R to the power of the forward propagated Rayleigh scattering effect P_T, in accordance with the following equation:

$$\frac{P_r}{P_t}[\mathrm{dB}] = -70 + 10\log_{10}(\Delta L) - \frac{\Delta Z}{100}. \tag{41}$$

b. Laser Phase Locking Means.

Refer to FIG. **3**. Local oscillator laser, **45**, generates a local oscillator lightwave. The local oscillator lightwave propagates from local oscillator laser, **45**, to optical coupler or beamsplitter, **43**. The optical coupler, **43**, splits off the smaller portion of power of the local oscillator lightwave into optical pathway, **41**. Optical path, **41**, propagates the smaller portion of the local oscillator lightwave to the phase locking means optical receiver, **35**. The larger portion of the power of the local oscillator lightwave is split off by optical coupler **43**, and passed to optical path **13**. Optical pathway, **13**, propagates the larger portion of the local oscillator lightwave to optical receiver, **15**. The phase locking means optical receiver, **35**, receives and interferes the transmitter laser lightwave from optical pathway, **39**, and the local oscillator lightwave from optical pathway **41**. The receiver **35** interferes the reference lightwaves from lasers **3** and **45** producing an electrical output which is a radio frequency wave on electrical pathway, **33**. The electrical output, **33**, provides an electronic beat frequency which directly indicates the difference in optical frequency and phase between lasers **1** and **45**. Phase locking circuitry **31**, employing a conventional phase lock loop mechanism, controls the difference in frequency between laser **1** and **45** and phase locks the two lasers to a fixed frequency and phase relationship as indicated by the dashed line between circuitry **31** and local oscillator laser **45**. The radian frequency difference is Δω as discussed early in the text. The purpose of the laser phase locking means is to insure that the local oscillator lightwave traveling on optical path, **13**, into optical receiver, **15**, has the proper phase and frequency relationship to the composite lightwave on optical pathway, **11**. It is to be appreciated that the phase locking mechanism also acts cooperatively with phase demodulator system **66** to be described later herein. Conventionally, a common master clock oscillator **311**, FIG. **7** provides the timing base for both phase locking circuitry **31** and an I & Q demodulator **300**, FIG. **7**.

Refer to FIG. **3**. The composite lightwave on optical path **11**, is an input into optical receiver **15**. The local oscillator lightwave on optical path, **13**, is also an input into optical receiver, **15**. The local oscillator and composite lightwaves are interfered on photodetectors producing an electronic signal which electronically represents the heterodyned optical interference power between the two lightwaves. The resulting composite radio frequency signal at output, **17**, represents electronically the composite lightwave signal on optical path, **11**. The composite electronic receiver signal is passed from optical receiver output, **17**, through amplifier, **19**, via electronic path, **21**, to the correlator system, **23**. The local oscillator lightwave on optical path, **13**, is interfered with the composite lightwave on optical path **11**. The interference power is photodetected in optical receiver, **15**, by optically interfering the composite back propagating lightwave on the local oscillator signal. As one of the components of this interfering action, there is produced a difference beat signal which is a composite radio frequency representation of the composite light wave on optical path, **11**.

This interfering of the local oscillator output lightwave **13** and the composite back-propagating CW lightwave **11** provides the translation of signal **11** from the optical domain to a CW radio frequency (r.f.) composite difference beat signal **17**. This reduces the frequency of signal **15** into an electronically processable signal frequency range. It is to be appreciated that an important aspect of the present invention that the r.f. composite difference signal produce by this translation action includes having counterpart components of the aforesaid components of the composite back-propagating lightwave signal, with the phase states of these counterpart r.f. domain signals the same as the phase states of the corresponding components of the back-propagating lightwave.

In accordance with the present invention, lasers **3** and **45** are to have sufficiently stringent high performance capability with respect to exactness of frequency to enable interference effects therebetween and heterodyne detection of acoustic perturbation signals incident to fiber **9** to produce beat frequencies within the radio frequency (r.f.) range. Also in accordance with the present invention, lasers **3** and **45** have stringent performance criteria with respect to the phase stability, or coherence, of their beams. They are to be substantially coherent over at least a propagation path distance substantially equal to twice the length, L, of sensing fiber **9**. For example, a commercially available non-planar, ring laser (e.g. Lightwave Electronics Corp. Model 125) would be suitable for an intruder sensing perimeter intrusion monitoring fiber **9** having a length of 8.0 km (approximately 5 miles). The laser beam of this commercially available laser, which is in the near infrared range, has a frequency of 227 terahertz, or 1319 nanometer wavelength, and has a frequency stability accurately within one part in a billion over 1 millisecond period, or 5 Kilohertz in a 1 millisecond period.

It is to be appreciated that the provision of such frequency and phase stability of lasers **3** and **45** enables implementing the phase locking to produce a sufficiently small non-zero radian phase locking circuitry **31**. This in turn enables lasers **3** and **45**, under regulation by phase locking circuitry **31**, to provide a pair of beams which are phase locked and with a "non-zero Δω" sufficiently small to enable a heterodyne-mode optical receiver to provide the desired beat frequency outputs in the r.f. range. It is understood that laser **45**, optical receiver **35**, circuitry **31** and beamsplitter **43** could be replaced with an apparatus applying the non-zero ΔW to the beam from optical pathway **39** to give the same result. The returned interrogation optical composite wave is defined in the preceding subsection **3**(*a*) "Optical Transmitter and Time-delay Multiplexing Process" of this DESCRIPTION OF THE PREFERRED EMBODIMENT.

In the preceding section (1) "Description of Underlying Theories" of this DESCRIPTION OF THE PREFERRED EMBODIMENT there is a definition of "non-zero Δω" and a mathematical demonstration of its importance in the heterodyne mode of interfering. It makes it possible to use relatively simple processes to avoid fading. By way of contrast, fading with the "zero Δω" homodyne mode of interfering would entail much more difficult and less effective fade avoidance processes.

c. Correlation Time-Delay Demultiplexing.

Refer to FIG. **3**. The composite radio frequency signal on electrical path, **21**, is input into the correlator system, **23**. The correlator system delays the master correlation code generator output, **51**, an appropriate amount and correlates the delayed correlation code with the composite radio frequency signal. This produces electrical outputs $O_1, O_2 \ldots O_n$ corresponding to signals $S_1, S_2 \ldots . S_n$, in turn corresponding to spatial delays $L_1, L_2 \ldots L_n$. The spatial delays $L_1, L_2 \ldots . L_n$ are arbitrary and programmable. The electrical output O_1 corresponds to $B(t,L_1)$ referred to in the preceding subsection **2**(*a*).

The correlation process is well understood in the literature. The signal that represents the backscattered optical wave in array, **9**, that is passed from the optical receiver **15**, to the correlator system **23**, contains all of the information for all sensors or channels $S_1, S_2 \ldots . S_n$ at once on the electronic signal path **21** entering the correlator **23**. Because the backscattered composite signal is modulated with the correlation code by modulator **5**, the backscattered light is time structured with the time structure of the correlation code. Because the correlation code is selected to have special autocorrelation code properties, the time structure of the correlation codes allows an electronic representation of the backscattered light at positions $L_1, L_2 \ldots L_n$ to be obtained via the correlation process in the correlator **23**. In a preferred embodiment of the invention the master code generator **53** is a shift register type pseudorandom number (PRN) code generator and each correlator of the set **23** would be a correlation type demodulator herein later described in greater depth. Code generator **53** may alternatively be embodied as a binary sequence having transorthogonal autocorrelation properties (binary pseudonoise sequence) and each correlator would then be a correlation-type demodulator for demodulating a binary pseudonoise sequence, whose implementation would be understood by those of skill in the art. The correlator uses the reference correlation code from correlation code generator, **53**, which is passed via electronic path **51** to the correlator, **23**, as a "golden ruler" enabling sorting out by temporal and spatial domain demultiplexing electronic representations of the backscattering optical signals at sensors or channels S_1, $S_2 \ldots S_n$. Various delayed versions of the correlation code are multiplied by the composite signal with all of the sensor or channel signals present simultaneously, from electronic path **21** so that the electronic representations of the sensors or channels $S_1, S_2 \ldots S_n$ are output from the correlator, **23** on signals $O_1, O_2 \ldots O_n$ with respect to the index.

Correlator system **23** is an electronic spread spectrum signal de-spreader and temporal and spatial domain demultiplexer of the r.f. signal counterpart to the optical composite signal. Its input is coupled to the amplified output **21** of the heterodyner and photodetector, and it is operative in cooperation with said source of spectrum spreading signals to perform a coherent signal correlation process upon the r.f. counterparts of the aforesaid "one" and the aforesaid "still another" components of the composite back-propagating CW lightwave. This causes the de-spreading of the r.f. counterpart of the optical reflected spread spectrum signal and causes the temporal and spatial demultiplexing of the r.f. counterpart of the "still another" component of the composite r.f. signal. This processing provides signals which temporally and spatially sort the said "still another" component into n virtual sensor signal channels, or stated another way n of each of the ΔZ length measurement regions, measuring the induced optical path change at each of the n ΔZ-length segments of the optical fiber span **9**.

It will be appreciated that this sorting process is accomplished by the autocorrelation properties of the spectrum-spreading signal and by the time of flight of the optical spectrum-spreading signal down to each nth reflection segment and back to the heterodyne optical receiver **15**. A delayed replica of the spectrum-spreading signal is correlated against the r.f. signal counterpart of the optical composite back-propagating signal, thereby segmenting the optical fiber into n independent segments, or virtual sensors, via the time of flight of the optical composite back-propagating signal and the autocorrelation function of the transmitted spectrum-spreading signal.

It is to be appreciated that system **2** is operating in the spread spectrum transmission and reception mode. Namely, by providing optical interrogation light wave, $E_1(t)$, with modulation by the correlation code, c(t), the continuous wave carrier signal is temporally structured into a spread spectrum interrogation lightwave which continuously reiterates autocorrelatable code sequences. Then after correlation system provides an appropriate time of delay the correlator system **26** correlates the backscattered light wave $E_b(t)$ with the same output, c(t), of code generator **53**, de-spreading the spread spectrum signal.

In accordance with well known communication electronics theory this has the effect of increasing signal output of the ROSE sensor system while the noise bandwidth remains the same. In temporally and spatially sorting the r.f. counterpart of the aforesaid "still another" component of the composite back-propagation lightwave, the aforesaid "another" component of undesired noises, such as reflections from couplers in fiber span **9**, are materially attenuated.

More particularity, in accordance with this well known theory, the signal-to-noise ratio (SNR) is enhanced by considerable attenuation of noise mechanisms in frequency ranges outside of center frequency lobe of the autocorrelation function and outside the pair of first side lobes to one and the other side of the center frequency lobe.

An illustrative embodiment of electronic spread spectrum signal de-spreader and spatial de-multiplexer for cooperation with the previously described shift register type PRN code generator may comprise a series of n like-shift register code generators respectively receiving the spectrum spreading signal through a corresponding series of n feed channels which cause delays which incrementally increase by an amount of time bearing a predetermined relationship to the fiber span length, and C_L, the speed of light through the fiber. The composite r.f. signal is fed to a corresponding series of n multipliers connected to receive as the other multiplier the codes generated by the respective de-spreader and demultiplexer to thereby provide the de-spread and de-multiplexed signal.

d. Heterodyne Phase Demodulation.

Refer to FIG. **3**. After the composite radio frequency signal on electrical path **21** is correlation time-delay demultiplexed by the correlator system, **23**, the plurality (which upwardly may include a very large number, for instance 5,000) of outputs $O_1, O_2 \ldots O_n$, on the plurality of electrical paths **61**, **63** and **65** respectively are phase demodulated by a plurality of individual phase demodulations in the phase demodulator system, **66**. The outputs of the phase demodulator system, **66**, are the corresponding plurality of electrical paths **71**, **73**, and **75**. The phase demodulator outputs **71**, **73**, and **75** correspond to the correlator outputs ($O_1, O_2 \ldots O_n$) **61**, **63** and **65** respectively, and to the corresponding plurality of corresponding signals $S_1, S_2 \ldots S_n$ respectively corresponding to spatial delays $L_1, L_2 \ldots L_n$ respectively. The outputs **71**, **73**, and **75** electronically indicate (with tens of kilohertz potential bandwidth) the phase states of optical signals $S_1, S_2 \ldots S_n$. In particular, output **71** is proportional to the temporal phase Φ_1 of $B(t, L_1)$ hereinbefore discussed in subsections 1(b) "Correlation or Time-delay Multiplexing" and 3(c) "Correlation Time-Delay Demultiplexing" of this DESCRIPTION OF THE PREFERRED EMBODIMENT. The phase demodulator outputs **73** and **75** indicate the temporal phase states Φ_2 and Φ_n of $B(t,L_2)$ and $B(t,L_n)$ respectively.

e. Fading Free Polarization Processing

Preferably system **2** further includes polarization signal characteristic processing functions (not shown), which are used together with the previously described feature that the heterodyning function provides in reducing fading, of the backscattering signal, $E_b(t)$. These polarization processing functions are disclosed in the commonly assigned U.S. Pat. No. 6,043,921 entitled "Fading-Free Optical Phase Rate Receiver," hereby incorporated herein in its entirely. The optical heterodyning feature which provides benefit in reducing fading includes: (i) cooperation of phase locked lasers **3** and **45** in the formation of the optical interrogation light wave, $E_1(t)$, applied to optical fiber **9**, or other linearly extended light propagation medium producing Rayleigh effects backscattering, and (ii) the manipulation of this by optical receiver **15** to provide the composite electronic receive signal as optical receiver output **17**. This takes advantage of the feature of more favorable Heterodyne fading conditions in a way, in which polarization and phase state signal fading is materially reduced in the detected backscattered light wave $E_b(t)$. The electronic decoding module 700 of U.S. Pat. No. 6,043,921 is substantially an equivalent to the correlator system herein. However, the system disclosed in U.S. Pat. No. 6,043,921 for implementing polarization fading reduction (if not substantially eliminating fading) is a generalized stand alone system for processing any optical phase signal having temporally varying polarization, phase, and phase frequency. It must be adapted for application to system **2** by appropriate integration into system **2** included the two following alternative approaches.

One approach for such adaptation passes the fade-free optical phase rate (FFOPR) photoreceiver RF signal to the correlator **23**, performs the correlation on the RF signal and completes the Phase Demodulation by In phase and Quadrature phase (hereinafter I & Q) demodulating the correlated RF signal into outputs. This method creates low bandwidth I & Q components and therefore requires low bandwidth analog-to-digital converters (implying a requirement for a large number of analog RF correlation electronic components). This RF correlator approach requires two correlator circuits for every virtual sensor element, or spatial channel, along fiber **9**. One correlator is needed for the vertical polarization RF signal path and one correlator is needed for the horizontal polarization RF signal path.

Another approach applies the I & Q demodulator of FIG. **7** of the U.S. Pat. No. 6,043,921 prior to correlation. This approach therefore correlates a wideband set of four I & Q signals. One I, Q, set is for horizontal polarization and the other I, Q, set is for the vertical polarization. In this case the I & Q signals are the I & Q signals for the whole virtual array rather than for one virtual sensor element of the array. Four correlators are required for each sensor element. One correlator is applied to each of the four wide bandwidth I & Q signals for each virtual sensor element. This second approach requires very wideband analog-to-digital converters, but allows digital correlators to be used instead of analog RF correlators. The RF correlator or first approach requires far more analog to digital converters and RF electronics. The digital correlator approach enables the correlators to be implemented by the digital approaches of massively integrated logic circuits and/or programmed processors, requiring far more digital logic, but substantially reducing the r.f. electronics and number analog-to-digital converter units in the system.

f. Phase Differencing

Refer to FIG. **3**. The plurality (which upwardly may include a very large number, for instance 5,000) of signals indicating the phase states $\Phi_1, \Phi_2 \ldots \Phi_n$ on electrical paths **71**, **73** and **75**, respectively, are input into the phase differencer, 99. The phase differencer forms a corresponding plurality of outputs **91**, **93** and **95** which are arbitrarily and programmably assigned as the subtractions of any two pairs of phase signals Φ_j and Φ_k (where j and k are selected from 1, 2 . . . n).

Each of the programmably selectable pairs of differenced phase signals form a signal $\Delta\Phi_{kj}$ which is spatially bounded within the region of the fiber between lengths L_j and L_k. The phase differencer therefore produces differential phase outputs corresponding to a set of programmable length and position virtual sensors.

Stated another way, each programmable selection of pairs of phase signals forms a virtual spatial differential sensor which senses the difference between the phases of the $\Delta\omega$ output of the photodector sub-system (which is the subject of the next subsections) in receiver **15**. Each $\Delta\omega$ is an r.f. difference beat signal representative of the aforesaid "still another" component of the composite back-propagating CW lightwave signal which passes from the launch end of fiber span **9** to directional coupler **7**. These signals from each pair therefore represent signals of virtual spatial differential sensors along fiber span **9**. As a result of the choice of pairs being selectively programmable these virtual sensor can be employed to implement adaptive apertures in processing signal incident the fiber span. This feature would be useful, for example, in enabling security system operators to classify objects causing acoustic pressure wave signals incident up a fiber span **9** used as a perimeter intrusion monitoring line.

g. Optical Detector Sub-System.

The optical receivers **15** and **35**, FIGS. **3**, **4** and **5**, are comprised of photodetector sub-systems. Any of the many well known photodetecting techniques and devices may be employed. Possible implementation of the photodetection sub-systems will now be discussed.

Refer to FIG. **4**. Like parts correspond to like numbers. Optical signals enter the photodetector sub-system via optical paths **101** and **103** which are extensions of the paths **11** and **13** in the case of receiver **15**, and (not shown) of paths **39** and **44** in the case of subsystem **35**. The optical signals are equally split by optical coupler or beamsplitter, **105**. The optical signal on path **107** is composite signal comprised of half the optical power of path **101** and half of the optical power arriving on pate **103**. The optical signal on path **107** is illuminated on optical detector **111**. The photo-current of optical detector **111** flows into electrical conductor **115**. Likewise, the optical signal on path **109** is comprised of half the optical power on path **101** and half of the optical power on path **103**. The optical signal on path **109** is illuminated on optical detector **113**. The photo-current of optical detector **113** flows out of electrical conductor **115**. Therefore the photo-currents of optical detectors **111** and **113** are subtracted at electrical conductor or node **115**.

Photo-detectors **111** and **113** are precisely matched in responsivity. The differential photocurrent on electrical conductor **115** is input into pre-amplifier **117**, amplifier and is passed to electrical output **119**. The differential nature of the photo-detection rejects either of the self-optical interference power of the signals on paths **101** and **103** and receives only the cross-interference power between the two optical signals on paths **101** and **103**. This particular optical detector architecture is called a balanced heterodyne optical detection scheme. The scheme is 3 dB more sensitive than all other heterodyne optical detection methods and offers the distinct advantage of rejecting local oscillator noise.

Refer to FIG. **5**. FIG. **5** illustrates an alternative photodetection scheme to FIG. **4**. lightwaves enter the receiver at paths **101** and **103**. The optical coupler or beamsplitter **105** combines the lightwaves on paths **101** and **103** into a composite lightwave on path **107**. The composite lightwave on path **107** illuminates optical detector **111**. The photocurrent of optical detector caused by the self-interference and cross interference of lightwaves originating from optical paths **101** and **103** passes through conductor **115***a*, is amplified by pre-amplifier **117** and is passed to electrical output **119**.

The optical detector sub-system of FIGS. **4** and **5** correspond to optical receivers **15** or **35** of FIG. **3**. Paths **101** and **103** correspond to **11** and **13** and output **119** corresponds outputs **17** in optical receiver **15**. Paths **101** and **103** correspond to **39** and **41** and output **119** corresponds to output **33** in optical receiver **35**. Either of the photo-detection schemes of FIG. **4** or **5** can be used for the optical receivers **15** or **35**. However, the photodetection scheme of FIG. **4** is preferred.

h. Programmable Correlator System

Refer to FIG. **6**. The composite radio frequency signal, or r.f. composite reference beat signal, which electronically represents the received time-delay multiplexed optical signal, or composite back-propagation CW lightwave, $E_b(t)$, is input into the correlator system, **23**, at electrical input **21**. The composite radio frequency signal is n-way split with power splitter **203** into a plurality (which upwardly may include a very large number, for instance 5,000) of electronic pathways including **211**, **213** and **215**. The master correlation code, c(t), is input into the correlator system, **23**, at electrical input **54**. The correlation code is distributed to such a plurality of programmable delay circuits including **221**, **223** and **225**. Each programmable delay circuit delays the master correlation code by the delay required to decode/demultiplex each time-delay multiplexed channel. The plurality of programmable delay circuits including **221**, **223** and **225** output a plurality of delayed correlation codes including those on electrical pathways **231**, **233**, and **225** respectively. The corresponding plurality of delayed correlation codes including those on electrical pathways **231**, **233** and **235** are multiplied by a corresponding plurality of multipliers (or balanced mixers) including **241**, **243** and **245**, respectively, by the radio frequency signal on the plurality of electronic pathways including **211**, **213** and **215** which are amplified by a corresponding plurality of amplifiers including **261**, **263** and **265**, respectively, to produce the corresponding plurality of outputs including O_1, O_2, and O_n (on lines **61**, **63** and **65**) respectively. Each of the outputs therefore produces the corresponding demultiplexed signal which is time-gated by the corresponding time-delay of the correlation code. The correlator system **23** of FIG. **6** is an example implementation of the correlation system, **23**, of FIG. **3**.

The output O_1 corresponds to signal $B(t,L_1)$ which is hereinbefore discussed in subsections 2(a) "ROSE Optical Phase Sensor Interrogation Enables Sensor System" and 3(c) "Correlation Time-Delay Demultiplexing" of this DESCRIPTION OF THE PREFERRED EMBODIMENT. The output $O_1,O_2 \ldots O_n$ on lines **61**, **63** and **65**, respectively, correspond to signals S_1, $S_2 \ldots S_n$ which in turn are based upon the spatial delay associated with distance $L_1,L_2 \ldots L_n$ indicated in FIG. **3**. These spatial delays are based on the time of propagation for flyback travel along these distances, which are arbitrary and programmable. The time delay multiplexing of the optical signals comprising the composite back-propagating optical signal on path **11**, FIG. **3**, arise from a plurality (which upwardly may include a very large number, for instance 5,000) of spatial locations causing a like plurality of time-delays. The correlator system spatially separates the components of the r.f. composite difference beat signal into channels which each uniquely represent an optical signal at a single spatial location.

The correlator system allows the spatial sampling of the optical signals so that a virtual array can be formed along the fiber span **9** on FIG. **3**.

i. Phase Demodulation System

The embodiment of phase demodulator system, **66**, of FIG. **3**, has two uses in system **2**. It either: (i) receives the outputs of the just described r.f. correlator subsection **23**, or (ii) is part of the integration of the polarization fading reduction system of U.S. Pat. No. 6,043,921 (as discussed in the preceding subsection 2(*e*) "Fading-Free Polarization Processing" of this DESCRIPTION OF THE PREFERRED EMBODIMENT. Refer to FIG. **7**. The phase demodulation system, **66**, is comprised of a plurality (which upwardly may include a very large number, for instance 5,000) of phase demodulators, **81**, **83** and **85**. The inputs to the plurality of phase demodulators, **61**, **63** and **65** (the correlator outputs O_1, $O_2 \ldots O_n$ discussed previously) are phase demodulated with phase demodulators **81**, **83** and **85** respectively. The outputs of these demodulators are passed on electrical pathways **71**, **73** and **75** respectively.

Refer to FIG. **8**. An example block diagram of any one of the just discussed phase demodulators **81**, **83** and **85** is shown as part **300**. The input electrical path **301** corresponds to any one of electrical path **61**, **63**, **65**, etc. of the plurality of phase demodulators. The output electrical path **319** corresponds to any one of electrical path **71**, **73**, **75**, etc. of the plurality of phase demodulators. A correlation system output such as O_1, O_2 or O_n is passed via electrical path **301** into a bandpass filter **303**. The bandpass filter **303** passes only a band of radian frequencies in the vicinity of $\Delta\omega$ so that only $B(t,L_m)$ passes through the filter (where m is an integer corresponding to the particular channel). The band passed signal passes from **303** via electrical path **305** to amplitude control **307**. Amplitude control **307** is either an analog automatic gain control circuit, an electronic clipper circuit, or a combination thereof. The amplitude control **307** removes amplitude variations due to polarization fading or other types of signal fading. Because the signal, $B(t,L_m)$ is a result of a heterodyne interference, the phase remains the same after clipping. It is to be appreciated that other phase demodulation schemes for fiber optic signals use a phase carrier technique which does not allow the clipping operation. Clipping is a preferred amplitude control mechanism. The amplitude control **307** passes an amplitude stabilized signal via electrical path **309** to I & Q demodulator **311**. The I & Q demodulator removes the carrier, that is it shifts the center radian frequency of the amplitude stabilized $B(t,L_m)$ from $\Delta\omega$ down to zero. The I & Q demodulator outputs a voltage proportional to $\cos(\Phi_m)$ on electrical path **313** and a voltage proportional to $\sin(\Phi_m)$ on electrical path **315**. The $\cos(\Phi_m)$ and $\sin(\Phi_m)$ proportional voltages on electrical paths **313** and **315** respectively are converted in an output signal proportional to Φ_m on electrical path **319** by the phase detector **317**.

Reviewing the previous discussion, the plurality of phase demodulators **81**, **83** and **85** of FIG. **7** each function like the block diagram of **300** on FIG. **8**. The plurality (which upwardly may include a very large number, for instance 5000) of phase demodulators **300** convert to a like plurality of signals $B(t,L_1)$, $B(t,L_2) \ldots B(t,L_n)$ into a like plurality of signals proportional to Φ_1, $\Phi_2 \ldots \Phi_n$ which correspond to optical signals S_1, $S_2 \ldots S_n$.

j. I & Q Demodulator.

An example implementation of the I & Q demodulator **311** of FIG. **8** will now be presented. Refer to FIG. **9**. An amplitude stabilized $B(t,L_m)$ signal (originating from the amplitude control **307** of FIG. **8**) is passed on electrical path **309** to a power splitter **403**. Half of the signal power exiting from power splitter **403** is passed to analog mixer, balanced mixer, Gilbert cell or analog multiplier **413** via electrical path **411**. The other half of signal power exiting form power splitter **403** is passed to analog mixer, balanced mixer, Gilbert cell or analog multiplier **423** via electrical path **421**.

The reference oscillator **451** generates an electronic wave proportional to cos(Δωt). As noted earlier herein, this reference oscillator is also the oscillator employed in the conventional phase lock mechanism establishing the fixed phase relationship between the frequencies of primary laser **3** and local oscillator laser **45** whose differences in frequency, ΔW, are of a very low order. In accordance with known principles of heterodyning lightwaves having fixed phase relationships, heterodyning these signals can produce a difference beat signal small enough to be in the r.f. signal range, but with the frequency difference sufficiently high to provide the heterodyning with a band pass allowing transforming a given binary code rate into corresponding code components of the beat signal, such as the code rate of the PRN code sequence produced by PRN code generator **53**. This reference oscillator wave is passed from the reference oscillator **451** via the electrical path **453** to amplifier **455**. The wave is amplified by amplifier **455** and passed to hybrid coupler **459** via electrical path **447**. The hybrid coupler splits the amplified reference oscillator electronic wave into two components one proportional to cos(Δωt) on electrical path **417** (providing the "I", or In-phase reference); and one proportional to sin(Δωt) on electrical path **427** (providing the "Q", or Quadrature-phase reference).

The In-phase reference on electrical path **417** is multiplied (or frequency mixed) with the signal on electrical path **411** by multiplier **413** to produce the output on electrical path **415**. The signal on electrical path **415** is amplified by amplifier **431** and passed to electronic lowpass filter **435** via electrical path **433**. The lowpass filter **435** removes high frequency components of the multiplication or frequency mixing process and results in an output at electrical path **313** which is proportional to cos(Φ_m).

The Quadrature-phase reference on electrical path **427** is multiplied (or frequency mixed) with the signal on electrical path **421** by multiplier **423** to produce the output on electrical path **425**. The signal on electrical path **425** is amplified by amplifier **441** and passed to electronic lowpass filter **445** via electrical path **443**. The lowpass filter **445** removes high frequency components of the multiplication or frequency mixing process and results in an output at electrical path **315** which is proportional to sin(Φ_m).

k. Phase Detector

Example implementations of the phase detection **317** of FIG. **8** will now be presented. Refer to FIG. **10**. An example digital phase detector implementation, **317**, is shown in the block diagram. The signal proportional to cos(Φ_m) on electrical path **313** is converted to a digital code or number by analog-to-digital converter (hereafter, A/D) **513**. The digital number proportional to cos (Φ_m) is input into the digital signal processor **501** via electrical path **515**. The signal proportional to sin (Φ_m) on electrical path **315** is converted to a digital code or number by A/D **523**. The digital number proportional to sin(Φ_m) is input into the digital signal processor, **501**, via electrical path **525**. The digital signal processor converts the numbers proportional to sin (Φ_m) and cos (Φ_m) into a number proportional to Φ_m as follows.

Suppose the constant of proportionality for the sin(Φ_m) and cos (Φ_m) is V_m. Then the digital signal processor can optimally select estimates of Φ_m and V_m to minimize the calculated error function:

$$\epsilon(\hat{\Phi}_m,\hat{V}_m)=((V_m\cos(\Phi_m)-\hat{V}_m\cos(\hat{\Phi}_m))^2+(V_m\sin(\Phi_m)-\hat{V}_m\sin(\Phi_m))^2) \quad (42)$$

The digital signal processor can also calculate Φ_m directly by taking the inverse tangent function or the inverse cotangent function:

$$\Phi_m = a\tan\left(\frac{V_m\sin(\Phi_m)}{V_m\cos(\Phi_m)}\right) = a\cot\left(\frac{V_m\cos(\Phi_m)}{V_m\sin(\Phi_m)}\right) \quad (43)$$

If desired, the digital signal processor can also implement the differentiate and cross multiply (hereafter DCM) algorithm. The DCM method is as follows. The digital representation of the signals proportional to sin (Φ_m) and cos(Φ_m) are temporally differentiated and cross multiplied by the non-differentiated signals. The result $U_m(t)$ is integrated to produce the desired output, Φ_m. Mathematically, this algorithm is:

$$U_m(t) = V_m\sin(\Phi_m)\frac{\partial}{\partial t}(V_m\cos(\Phi_m)) - V_m\cos(\Phi_m)\frac{\partial}{\partial t}(V_m\sin(\Phi_m)) \quad (44)$$

$$U_m(t) = V_m^2((\cos(\Phi_m))^2 + (\sin(\Phi_m))^2)\frac{\partial\Phi_m}{\partial t}$$

$$U_m(t) = V_m^2\frac{\partial\Phi_m}{\partial t}$$

$$\Phi_m = \frac{1}{V_m^2}\int U_m(t)\partial t.$$

The digital signal processor **501** converts the signals arriving on electrical paths **515** and **525** into a digital output proportional to Φ_m on electronic path **503**. Optionally, the digital output is passed on electronic path **505** to some other data sink such as a computer memory. The digital signal proportional to Φ_m on electronic path **503** is converted back to an analog signal on electrical path **319** by digital-to-analog converter **507**. By way of a summarization, the example digital phase detector **317** accepts inputs **313** and **315** which originate from the I & Q demodulator, **311**, of FIG. **8**, and the digital phase detector **317** outputs the phase signal Φ_m on electrical path **319**. Optionally, any of other well-known implementations of digital phase detectors may be employed.

Refer to FIG. **11**. An example analog phase detector implementation, **317'** is shown in the block diagram. The example analog phase detector **317'** shown in FIG. **11** implements an analog version of the DCM algorithm discussed in the previous text. The signal proportional to cos (Φ_m) on electrical path **313** is input into analog temporal differentiator **613** and analog multiplier **617**. The signal proportional to sin(Φ_m) on electrical path **315** is input into analog temporal differentiator **623** and analog multiplier **627**. The differentiated cosine term on signal path **625** is multiplied by the sine term on electrical path **315** by analog multiplier **627** producing the signal on electrical path **629**. The differentiated sine term on electrical path **615** is multiplied by the cosine term on electrical path **313** by analog multiplier **617** producing the signal on electrical path **619**. The signals on electrical paths **619** and **629** are applied as inputs to differential summer **631**. The output of differential summer on electrical path **633**, which is the result of the differentiated sine and cosine product being subtracted from the differentiated cosine and sine product, corresponds to $U_m(t)$ of the DCM discussion. The signal on electrical path **633** is integrated by analog integrator **635** to produce the analog phase detector output proportional to Φ_m on electrical path and output **319**. By way of summarization, the example analog phase detector **317** accepts inputs **313** and **315** which originate from the I & Q demodulator **311** of FIG. **8**, then the analog phase detector outputs the phase signal Φ_m on electrical path **319**. Optionally, any of other well-known implementations of analog phase detectors may be employed.

1. Programmable Phase Difference

The example programmable phase differencer implementation shown as part **99** of FIG. **12** corresponds to part **99** shown as a block in FIG. **3**. Refer to FIG. **12**. The plurality (which upwardly may include a very large number, for instance 5,000) of demodulated signals proportional to optical signal phases Φ_1, Φ_2 . . . Φ_n are input into the programmable phase signal switching and routing network **701** via electrical paths **71**, **73** and **75**, respectively. Network **701** programmably selects on a basis of timed relation to code generator **53** and routes on a basis of conventional "hold-in memory" and "transfer-from-memory", a plurality (which upwardly may include a very large number, for instance 5,000) of pairs of phase signals onto a plurality (which upwardly may include a very large number, for instance 5,000) of pairs of electronic paths **711** and **713**, **731** and **733** and **751** and **753**. The plurality of routed pairs of phase signals are applied to the corresponding of subtracters **715**, **735** and **755** as shown on FIG. **12**. The plurality of phase pairs on electronic pairs of paths **711** and **713**, **731** and **733**, and **751** and **753** are subtracted by subtracters **715**, **735** and **753**, respectively, and the differential signal are outputted on a corresponding plurality of electrical paths **91**, **93** and **95** respectively. The following description focuses on the differencing channel output on electrical path **91**, it being understood that the modes of operation of other differencing channels in network **701** are the same. Programmable phase switching and routing network **701** selects one of the phase signals on one of the plurality of electrical paths **71**, **73** or **75** and routes the signal to electrical path **711**. The signal on electrical path **711** is selected to be proportional to Φ_j (where j is of the set 1,2 . . . n). Network **701** also selects another of the phase signals on one of the other of the plurality of electronic paths **71**, **73** or **75** and routes the signal to electrical path **713**. The signal of electrical path **713** is selected to be proportional to Φ_k (where k is of set 1,2 . . . n). The signal on electrical path **711** is subtracted from the signal on electrical path **713** by subtracter **715**. The output of subtracter **715** is passed on via electrical path **91** and is proportional to $\Delta\Phi_{kj}$ hereinabove discussed in subsection 3(f) "Phase Differencing" of this DESCRIPTION OF THE PREFERRED EMBODIMENT. Employing this mode, network **701** programmably makes selection from optical signal phases Φ_1, Φ_2 . . . Φ_n to provide other differential phase outputs on electrical paths **91**, **93** and **95**. This may include a very large number of differential phase signals, for instance 5000. As an alternative to the just described type of circuitry employing subtracters **715**, **735** and **755** any of other well-known forms of producing a differential signal my be employed.

m. An Alternative Viewpoint of the Partitioning of System **2**.

As an alternative to the viewpoint inferable from the preceding sequence discussing FIG. **3**, system **2** may be considered as partitioned into: (i) an optical network for illuminating an optical fiber sensing span, or other light propagation medium sensing span, and retrieving back propagating portions of the illumination; and (ii) a photoelectronic network for establishing virtual sensors at predetermined locations along the span and picking up external physical signals incident to, or impinging upon, the sensors.

In general, the optical network for the illumination of, and for the retrieval of back-propagation from, fiber span **9** comprises transmitter laser **3**, directional optical coupler **7**, and optical fiber, or other light propagation medium **9**.

The photoelectronic network for establishing virtual sensors and picking up signals therefrom generally comprises two subdivisions. One subdivision provides a cyclically reiterative autocorrelatable form of modulation of the lightwave illuminating fiber span **9**. This modulation is in the form reiterated sequences having autocorrelatable properties. The other subdivision takes the retrieved back propagation and performs a heterodyning therewith to obtain an r.f. beat signal. It then picks up the signal from the virtual sensors by autocorrelation and further processes it into more useful forms.

In general, the subdivision providing the cyclical reiterative modulation of sequences illuminating fiber span **9** comprises master correlation code generator **53** (via one of its electrical pathway outputs) and optical modulator **5**.

In general, the subdivision for performing heterodyning with and picking up of virtual sensor signals from the retrieved back propagation from fiber span **9** includes local oscillator laser **45**, and the network which phase locks transmitter laser **3** and local oscillator **45**, and a sequence of elements which perform processing upon the retrieved back propagation. The phase locking network comprises beamsplitter **4**, phase locking means optical receiver **35**, phase locking circuitry **30**, and optical coupler **43**. First in the sequence of processing elements is an optical receiver **15** which photodetects interference power "derived" by heterodyning the back propagated illumination portion retrieved from fiber span **9** with the output of a local oscillator **45**. Lasers **3** and **45** are operated with a frequency difference to produce an r.f. beat signal, ΔW. Then correlation system **23** receives as one of its inputs another electrical pathway output from master correlation code generator **53**, and provides a series of channels which in turn respectively provide predetermined time delays in relation to the timing base of cyclic reiterative code generator **53**, to perform a series of autocorrelations of the respectively delayed inputs from code generator **53** with the signal ΔW. This picks up r.f. signals respectively representative of the affects in the lightwave domain of the external physical signals incident upon the respective virtual sensor. Phase demodulator system **66** provides a linear phase signal derived from such r.f. signals representative of optical signals at the respective virtual sensors. Programmable phase differencer **99** processes pairs of these linear phase signals occurring across segments of fiber span **9** between programmably selected pairs of the virtual sensors.

Following is another overview description which more particularly calls attentions to an aspect of the invention that the system elements which performs the autocorrelation enable providing an output in the form of an r.f. counterpart of a lightwave time-domain reflectometry output of signals incident to the virtual sensors as lightwave time domain reflectometry outputs a CW lightwave modulated by a continuously reiterated binary pseudorandom code sequence is launched into an end of a span of ordinary optical fiber cable. Portions of the launched lightwave back propagate to the launch end from a continuum of locations along the span because of innate fiber properties including Rayleigh scattering. This is picked off the launch end and heterodyned to produce an r.f. beat signal. The r.f. beat signal is processed by a plurality (which can be thousands) of correlator type binary pseudonoise code sequence demodulators respectively operated in different delay time relationships to the timing base of the reiterated modulation sequences. The outputs of the demodulators provide r.f. time-domain reflectometry outputs representative of signals (e.g., acoustic pressure waves) incident to virtual sensors along the fiber at positions corresponding to the various time delay relationships.

Following is still another overview description which more particularly calls attention to an aspect of the invention that the system elements performing the autocorrelation enable detection of unique spectral components representing a phase variations of external signals incident to the virtual sensors. A CW lightwave modulated by a continuously reiterated pseudorandom code sequence is launched into an end of a span of ordinary optical fiber cable. Portions of the launched lightwave back propagate to the launch end from a continuum of locations along the span because of innate fiber properties including Rayleigh scattering. This is picked off the launch end and heterodyned producing an r.f. beat signal. The r.f. beat signal is processed by a plurality (which can be thousands) of correlator type pseudonoise code sequence demodulation and phase demodulator units, operated in different time delay relationships to the timing base of the reiterated modulation sequences. These units provide outputs representative of phase variations in respective unique spectral components in the r.f. beat signal caused by acoustic, or other forms of signals, incident to virtual sensors at fiber positions corresponding to the various time delay relationships.

Following is yet another overview description which more particularly calls attention to an aspect of the invention that a pair of the different delay time relationships of the autocorrelation system elements are effective to establish a virtual increment of the optical fiber span, and that a substracter circuit of phase differencer **99** enables representing the differential phase signal across the virtual increment. A CW lightwave modulated by a continuously reiterated pseudorandom (PN) code sequence is launched into an end of a span of ordinary optical fiber cable. Portions of the launched lightwave back propagate to the launch end from a continuum of locations along the span because of innate fiber properties including Rayleigh scattering. This is picked off the launch end and heterodyned producing an r.f. beat signal. The r.f. beat signal is processed by a plurality (which can be thousands) of correlator pseudonoise code sequence demodulation and phase demodulator units operated in different delay time relationships to the timing base of the reiterated modulation sequences. Pairs of outputs of the units are connected to respective substracter circuits, each providing a signal representative of phase differential of incident acoustic signals, or other forms of signals, across virtual increments of the span established by a pair of said delay time relationships.

n. Air-Backed Mandrel Modified Form of Invention

FIG. **13** illustrates a so-called fiber-on-an-air-backed mandrel assembly **801**, useful in applications in which a fiber optic span **9'** is to be immersed in a liquid medium. Assembly **801** comprises a hollow cylindrical mandrel **803** having formed therein a sealed central chamber **805** containing air or other gaseous medium **807**, which is compressible relative to the liquid medium. A segment of span **9'** of a ROSE system **2**, FIG. **3**, is helically wound the cylindrical exterior surface of mandrel **803**, and suitably fixedly bonded to the surface. The cylindral wall **809** of mandrel **803** is of a material so chosen and of a thickness so chosen to form a containic membrane with a hoop stiffness that enables acoustic pressure wave signals incident upon assembly **801** to be transformed into mandrel radial dimensional variations. As a result of mandrel **801**'s geometry these radial variations result in magnified longitudinal strain variations in fiber **9'**. It is to be appreciated that the physical structure of assembly **801** inherently provides a spatial succession of two locations along the fiber span, which a phase signal switch and routing network **701** could select and route to become the virtual bounding positions of a differential phase signal virtual sensor. This is to say, positioning a mandrel wound span **9'** as a segment of a system total span **9** of ROSE system **2** can facilitate providing a sequential pair of virtual sensor locations along a span **9**, and the provision of a corresponding pair of delay circuits in correlator circuit **23** would cause assembly **801** to operate as a differential phase signal sensor.

(4) Advantages and New Features

The invention enables the interrogation or time-delay correlational multiplexing and demultiplexing of optical phase signals.

The invention enables the interrogation of ROSE (Rayleigh Optical Scattering and Encoding) fiber optic sensors. The invention enables the spatial sorting and separation of the temporal optical phases of backscattered optical signals arising from a plurality (which upwardly may include a very large number, for instance 5,000) of virtual optical sensors along fibers or other optical mediums. The invention enables the spatial decoding of backscattered optical signals with a bandwidth of tens of kilohertz. The invention enables the sensor locations along the fiber to be programmable. The invention allows the electronic separation or segmentation of the array of fiber sensors into programmable bounded lengths and positions. Because the correlation signal, c(t), can be designed to be a continuous wave, the invention increases the average optical power considerably over conventional pulsed optical phase sensor interrogation methods. Because the correlation signal c(t) can be chosen to have spectrum spreading properties for which dispreading electronic circuitry is readily available, undesired optical fiber system noises, such as reflection discontinuity noises due to cable couplings, can be materially attenuated.

In hypothetically assessing the potential achievable by the present invention with regard to employment of a common grade of optical fiber cable buried beneath the ground surface as a perimeter intrusion monitoring fiber span, the following assumptions have been made: (i) signal to noise ratio (S/N) degradation of Rayleigh effect light propagation in such an optical fiber cable are assumed to be 0.5 db/km; (ii) it is assumed there is a requirement for bandwidth of ten times that of the geo-acoustic intruder signal needs to be detected; (iii) and digital circuitry functions are performed employing conventional "high end" clock rates. Using these assumptions, and employing conventional single-mode or multimode fiber buried 6–12 inches underground, and using conventional engineering methodology for noise effect prediction, it can be shown that ROSE system **2** has the potential of sensing intruder caused geo-acoustic, (i.e., seismic) signals along a length of fiber span line as long as 8 km or 5 miles. (This assessment is based upon S/N degradations for flyback travel of signals from the interrogation launch end of fiber span **9** to its remote end and back.) The hypothetical segment resolution capability with such a 8 km., or 5 mile line, would be 1 meter.

The invention provides a new capability of heterodyne optical phase detection without resorting to dithered phase carrier methods. The phase demodulation method introduces heterodyne I & Q demodulation to produce cosine and sine phase components, clipped signal amplitude stabilization techniques and digital signal processing based phase detection. The spatially differential phase detection method provided by the invention enables the rejection of unwanted lead-in fiber phase signals.

The details, materials step of operation and arrangement of parts herein have been described and illustrated in order to explain the nature of the invention. Many modifications in these are possible by those skilled in the art within the teachings herein of the invention. For example, while in system **2** the transformation from optical to r.f. signal takes place prior to processing by programmable correlation **23**, it is within the skill of the art to design optical receiver **15** and correlator system **23** to have the transformation take place otherwise. Also, as an alternative to the previously described mechanism for phase locking laser **3** and **45**, the laser optical wave on an optical path **39** can be passed through an acoustic-optic modulator, sometimes called a Bragg Cell. The diffracted optical wave exiting the acousto-optic modulator will be Doppler shifted by an impinging-driving RF wave, that is translated into a sound wave in the acousto-optic modulator, and the so-called Bragg shifted-diffracted optical wave will exit the acousti-optical modudulator with an optical frequency equivalent to the phase locked laser **45**. The acousto-optically generated lightwave, at an equivalent frequency of the phase locked laser **45**, is sent along optical pathway **13** and becomes the local oscillator input to heterodyne photoreceiver **15**. An acousto-optically frequency shifted version of the light in optical path **39** can therefore replace the phase locked light of coherent optical source **45**. Accordingly it is to be understood that changes may be made by those skilled in the art within the principle and scope of the inventions expressed in the appended claims.

What is claimed is:

1. A time-domain reflectometer for sensing at a desired set of n spaced sensing positions along an optical fiber span, said sensing positions being for sensing a type of external physical signal having the property of inducing light path changes within the optical fiber span at regions there along where the signal is coupled to the span, comprising:

an optical fiber span having a first end which concurrently serves as both the interrogation signal input end and the back propagating signal output end for purposes of reflectometry, and having a second remote end;

a first light source for producing a coherent carrier lightwave signal of a first predetermined wavelength;

a binary pseudonoise code sequence modulator modulating said carrier signal for producing a pseudonoise code sequence modulated interrogation lightwave signal which continuously reiterates the binary pseudonoise code sequence, the reiterated sequences being executed in a fixed relationship to a predetermined timing base;

a lightwave heterodyner having first and second inputs for receiving a primary signal and a local oscillator signal, respectively, and operative to produce the beat frequencies of their respective frequencies;

a lightwave directional coupler having a first port which receives said binary pseudonoise code sequence modulated interrogation lightwave, a second port coupled to said first end of said optical fiber span, and a third port coupled to said primary signal input of the heterodyner;

said directional coupler coupling said binary pseudonoise code sequence modulated interrogation lightwave to said second port where it is launched in a forwardly propagating direction along said optical fiber span causing the return to said second port of a composite back-propagating lightwave which is a summation of lightwave back-propagations from a continuum of locations along the length of the span, said composite back-propagating lightwave signal comprising a summation of multiple components including

a first signal component comprising the summation of portions of the said pseudonoise code sequence modulated interrogation lightwave signal which the innate properties of the optical fiber cause to back-propagate at a continuum of locations along the span, and

a second signal component comprising the modulation of said first signal component caused by longitudinal components of optical path changes induced into said span at a continuum of locations along said span by external physical signals, said second signal component further including a corresponding set of subcomponents comprising the modulation of said first signal component by optical path changes caused by said external signals at the respective sensing positions;

said directional coupler coupling said composite back-propagating lightwave to said third port where it is applied to said first input of the heterodyner;

a second light source coupled to said second input of the lightwave heterodyner, said second light source producing a coherent local oscillator lightwave signal in phase locked relation to said carrier lightwave signal, said local oscillator signal being of a second predetermined wavelength which differs from the first predetermined wavelength by an amount of difference small enough to produce at the output of the heterodyner a radio frequency (r.f.) composite difference beat signal, but by an amount large enough to cause said r.f. composite difference beat signal to have sufficient bandwidth to cause it to include r.f. counterparts of signal components and subcomponents of said composite back propagating lightwave signal;

said r.f. composite difference beat frequency signal being coupled to an n-way splitter providing a corresponding set of n output channels, each transmitting said r.f. composite difference beat signal;

a corresponding set of n correlation-type binary pseudonoise code sequence demodulators having their respective inputs connected to the corresponding output channels of said n-way splitter through a corresponding set of time delay circuits which respectively provide a corresponding set of predetermined time delays in relation to said predetermined timing base of the binary pseudonoise code sequence modulator, to establish said n desired sensing positions along said optical fiber span; and

said set of correlation-type binary pseudonoise code sequence demodulators serving to conjunctively temporally and spatially de-multiplex said r.f. composite difference beat signal to provide at their respective outputs r.f. counterparts of the subcomponents of said second signal component of said composite back-propagating lightwave signal caused by changes in the optical path within said optical fiber span induced by external physical signals respectively coupled to the corresponding sensing positions.

2. The reflectometer of claim 1 wherein:

said innate properties of the said optical fiber material include the generation of Rayleigh optical scattering effects at a continuum of locations along said optical fiber span in response to said forwardly propagating binary pseudonoise code sequence modulated interrogation lightwave.

3. The reflectometer of claim 1 wherein said type of external physical signal which induces light path changes in said optical fiber span is an acoustic pressure wave signal.

4. The reflectometer of claim 3, wherein:

said optical fiber span is an acoustic security alarm perimeter monitoring line buried at a predetermined depth beneath the surface of the ground;

said acoustic pressure wave signal being caused by the vibration of the ground surface by movement of an object thereon; and

said set of n sensing positions along the line form a virtual array of n geophones which respectively produce substantially linear signals respectively representative of the vibrations of the surface of the ground at corresponding sensing positions.

5. The reflectometer of claim 4 wherein the range of depths of burial of the optical fiber span beneath the surface of the ground is of six inches to the order of one foot.

6. The reflectometer of claim 3 wherein:

said optical fiber span is of a length L; and

said first light source is a laser having the performance capability to generate a lightwave signal with sufficient phase stability to substantially retain coherency in propagation along said optical fiber span for a distance at least equal to 2 L.

7. The reflectometer of claim 6, wherein:

said the length L of said optical fiber span is at least 5.0 km.

8. The reflectometer of claim 7 wherein said first light source is a planar, ring-type laser.

9. The reflectometer of claim 3 wherein said optical fiber span comprises a single-mode fiber optic cable.

10. The reflectometer of claim 3 wherein said optical fiber span comprises a fiber optic cable of the polarization preserving type.

11. The reflectometer of claim 3, wherein:

said optical fiber span has a coating made of a thermoplastic material having the combined characteristics of a low Young's modulus and a Poisson's ratio below that of natural rubber; and

said coating serving to enhance the longitudinal component of strain variation derived from an acoustic wave signal whose wave front is incident to the span from a direction at least in part having a lateral component in the direction along which the wave front propagates.

12. The reflectometer of claim 1 wherein:

said lightwave heterodyner is of the photodetector type.

13. The reflectometer of claim 12 wherein:

said lightwave heterodyner of the photodetector type is a balanced optical detector circuit including a matched pair of photodetectors with the composite back-propagating lightwave signal applied to each photodetector of the pair; and

said balanced optical detection circuit produces said r.f. composite difference beat signal as a differential current from the matched pair of photodetectors.

14. The reflectometer of claim 1 wherein the continuously reiterated binary pseudonoise code sequences are binary pseudonoise sequences wherein shifts between binary states of the signal alternatingly shift the radian phase of the carrier between substantially 0° and substantially 180°.

15. The reflectometer of claim 1 wherein said pseudonoise code sequence is a pseudorandom number (PN) code sequence generated by a shift-register type PRN code generator.

16. The reflectometer of claim 1, and:

a fixed frequency reference oscillator which produces a reference phase signal;

each phase demodulator including an I & Q quadrature demodulator having a first input for receiving said reference phase signal and a second input for receiving an r.f. counterpart of the corresponding subcomponent of said second signal component of said composite back-propagating lightwave signal, said I & Q demodulator being operative to derive from said reference phase signal an interim in phase signal and an interim quadrature phase signal and to split the signal received at its second input and mix one part thereof with the interim in phase signal and another part thereof with the interim quadrature phase signal to provide a pair of output signals; and

each phase demodulator further including a phase detector having a pair of inputs for receiving respectively one and the other of said outputs of the I & Q demodulator and operative to provide at the output of the phase demodulator said signal representative of the radian phase of the respective subcomponent of said set of n subcomponents.

17. The reflectometer of claim 16, wherein said reference phase signal produced by said fixed frequency oscillator is used in establishing the phase locked relationship between the local oscillator lightwave signal and the carrier lightwave signal.

18. The reflectometer of claim 1, wherein:

a time period TP is required for forward propagation of said autocorrelatable spectrum spreading signal from the output of the source of the spectrum spreading signal to where said first light source is modulated, and then for the forward propagation of the derivative spread spectrum modulated interrogation lightwave signal to the second remote end of the fiber optical span, plus the time period required for the back propagation of a subcomponent of said composite back-propagating CW lightwave signal produced at the remote end of the span to the input of the heterodyner, and then for the back propagation of the derivative counterpart subcomponent of the r.f. composite difference beat signal from the output of the heterdyner to the input of a corresponding de-spreader and de-multiplexer of said set of n de-spreader and de-multiplexers; and

the temporal length of a single autocorrelatable spectrum spreading signal sequence of the continuously reiterated code sequences is one of one and the other of

less than the time period TP, and

greater than the time period TP.

19. The reflectometer of claim 1, wherein said type of external physical signal which induces light path changes in said optical fiber span is a selected one of a group consisting of: (i) a seismic signal wherein with the media which couples the signal to said optical fiber span includes at least in part the ground in which the fiber optic span is buried; (ii) an underwater sound signal wherein the media which couples the signal to said optical fiber span includes at least in part a body of water in which the fiber optic span is immersed; (iii) an electromagnetic force field coupled to the

optical fiber span; (iv) a signal comprising temperature variations coupled to the optical fiber span; and (v) at least one microphonic signal which is coupled to said optical fiber span at an at least one of said set of n sensing positions along the optical fiber span.

20. The reflectometer of claim **1**, wherein each of: (i) said coherent carrier lightwave signal; (ii) said coherent local oscillator lightwave signal; (iii) said spread spectrum modulated interrogation lightwave signal; (iv) said composite back-propagating lightwave signal; (v) said radio frequency (r.f.) composite difference beat signal; and (vi) each counterpart of said r.f. counterpart of the subcomponents of said second signal component of said composite back-propagating lightwave signal, is a continuous wave (CW) signal.

21. A system wherein, at respective sensing stations of a plurality of sensing stations along a span of optical fiber, the system senses input signals of a type having a property of inducing light path changes at regions of the span influenced by such input signals, comprising:

means for illuminating an optical fiber span with a CW optical signal;

means for retrieving back-propagating portions of the illumination back propagating from a continuum of locations along the span;

means for modulating said CW optical signal with a reiterative autocorrelatable form of modulation;

means for picking off a radio frequency (r.f.) counterpart of the retrieved signal, wherein the r.f. counterpart is in phase locked synchronism with the CW optical signal;

means for performing a corresponding plurality of autocorrelation detections upon said (r.f.) counterpart of the retrieved optical signal wherein said performing of the respective autocorrelation detections of the plurality of autocorrelation detection by said means for performing autocorrelation-detections are done in a corresponding plurality of different timed relationships with respect to the reiterative autocorrelatable form of modulation of the CW optical signal.

22. Signal sensing apparatus for sensing input signals at an array of a plurality of sensing stations along an optical fiber span, wherein at respective sensing station of the array the apparatus senses input signals of a type having the property of inducing light path changes within regions influenced by such input signals, said apparatus comprising:

an optical wave network comprising a transmitter laser and a lightwave directional coupler, said network being operative to illuminate an optical fiber span with a CW optical signal and to retrieve portions of the illumination back-propagating from a continuum of locations along the fiber span;

a modulator operative to modulate the CW optical signal in accordance with a reiterative autocorrelatable form of modulation code;

a heterodyner which, in phase locked synchronism with said transmitter laser, receives said retrieved back-propagated portions of illumination and derives therefrom a radio frequency (r.f.) counterpart; and

a corresponding plurality of autocorrelation detectors operative upon said r.f. counterpart of the retrieved optical signal in respective timed relationships of a corresponding plurality of different timed relationsips with respect to said reiterative autocorrelatable form of modulation code.

* * * * *

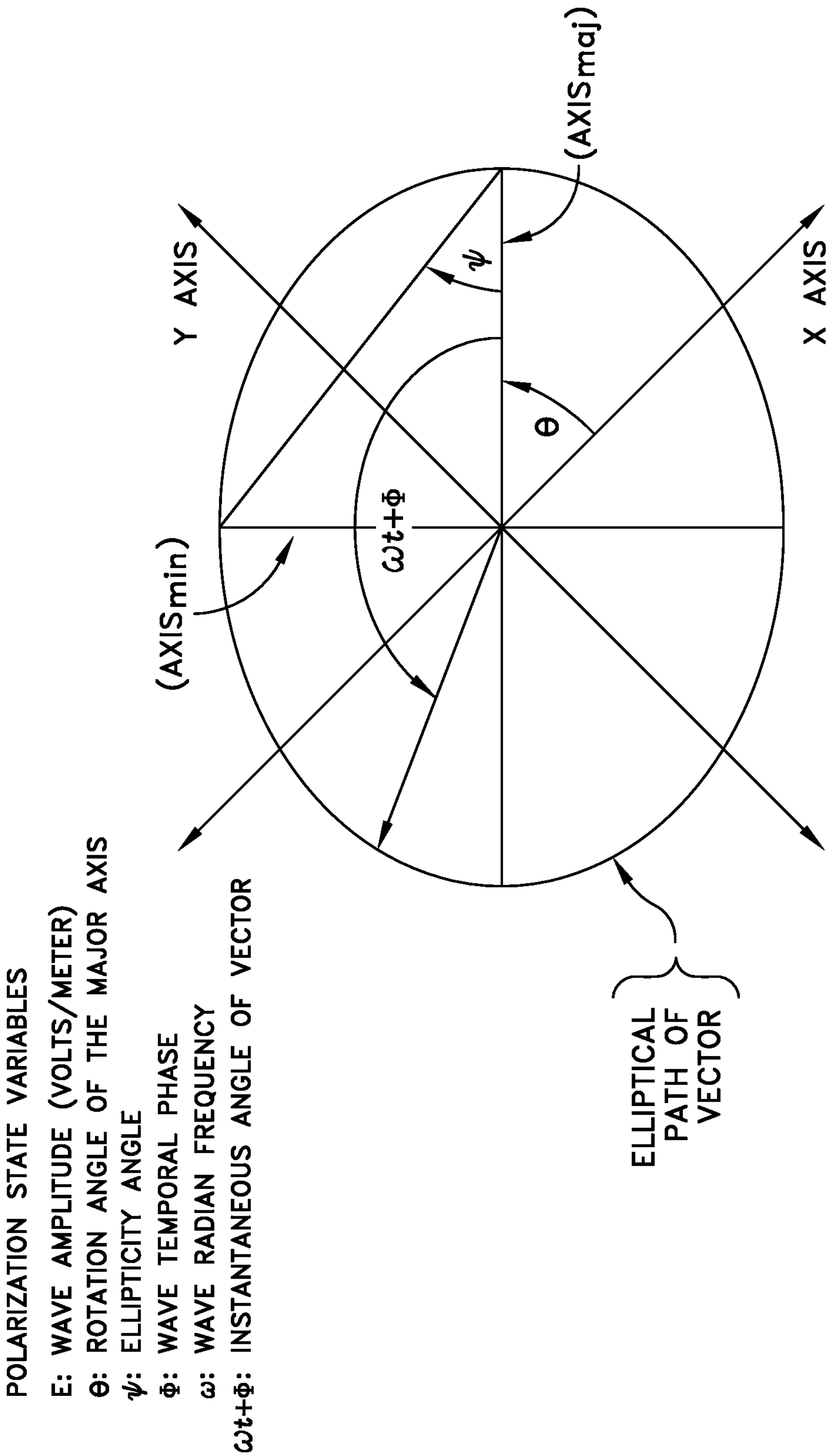

(AXISmaj)
ψ
Y AXIS
X AXIS
θ
ωt+Φ
(AXISmin)
ELLIPTICAL PATH OF VECTOR
POLARIZATION STATE VARIABLES
E: WAVE AMPLITUDE (VOLTS/METER)
θ: ROTATION ANGLE OF THE MAJOR AXIS
ψ: ELLIPTICITY ANGLE
Φ: WAVE TEMPORAL PHASE
ω: WAVE RADIAN FREQUENCY
ωt+Φ: INSTANTANEOUS ANGLE OF VECTOR

FIG. 1

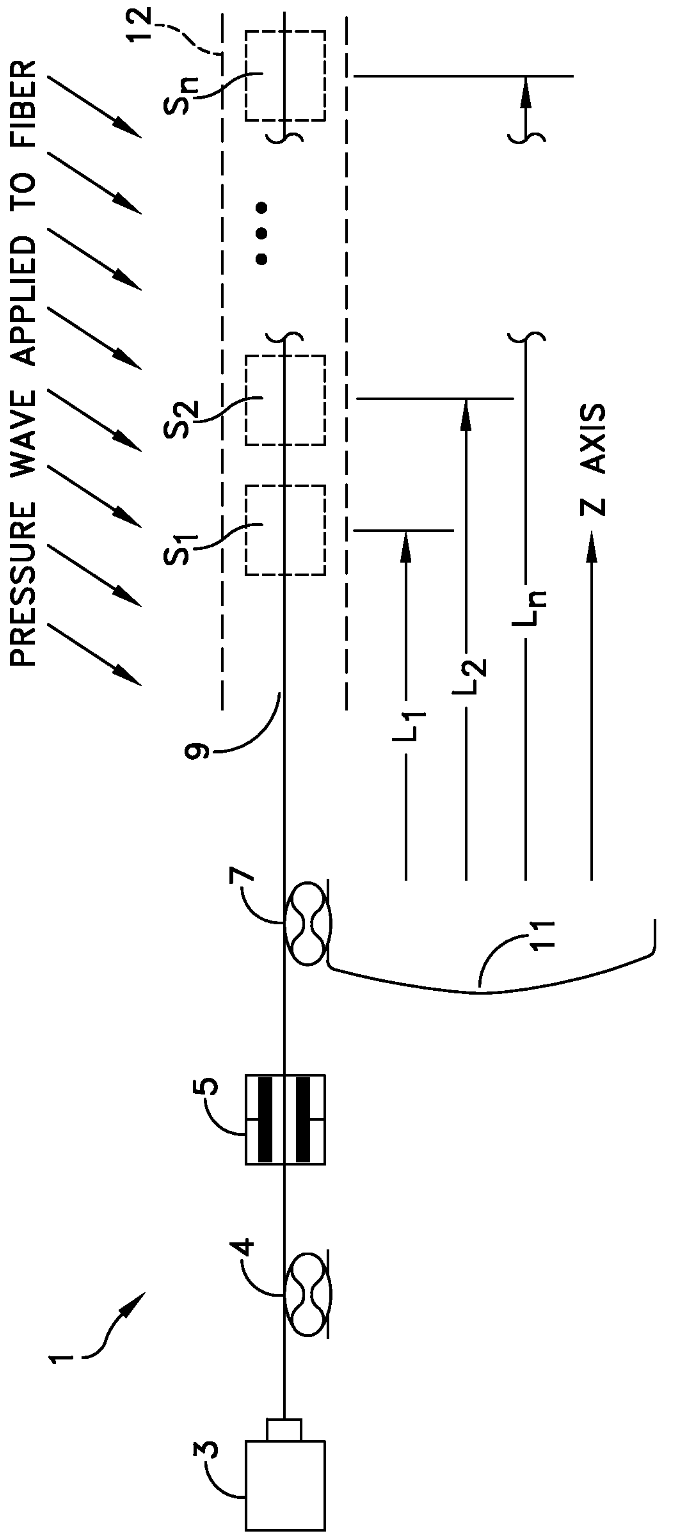
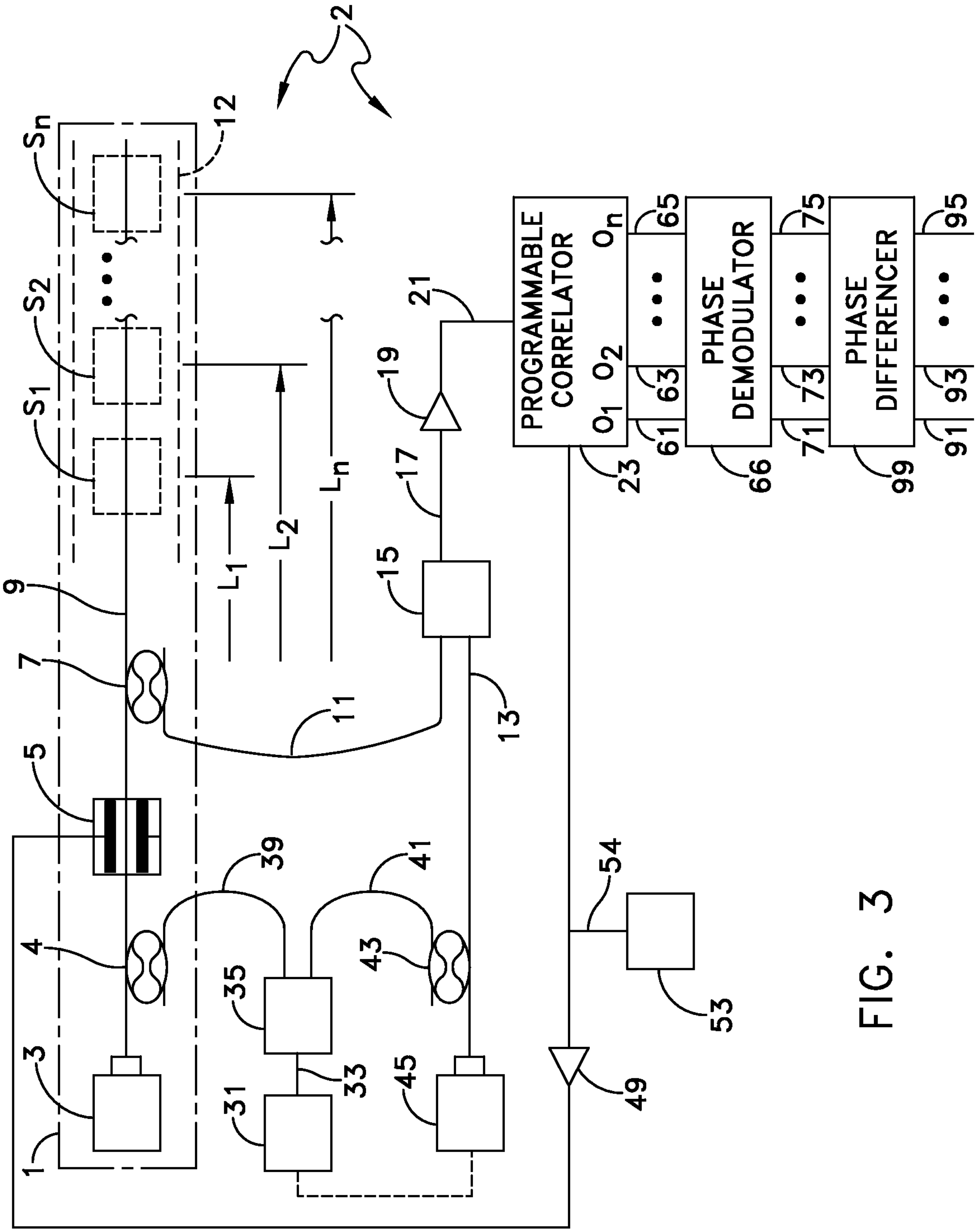

PRESSURE WAVE APPLIED TO FIBER
12
Sn
S2
S1
9
L1
L2
Ln
Z AXIS
7
11
5
4
1
3

FIG. 2


PROGRAMMABLE CORRELATOR
PHASE DEMODULATOR
PHASE DIFFERENCER
O_1
O_2
O_n
S_1
S_2
S_n
L_1
L_2
L_n
1
2
3
4
5
7
9
11
12
13
15
17
19
21
23
31
33
35
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43
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49
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54
61
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66
71
73
75
91
93
95
99

FIG. 3

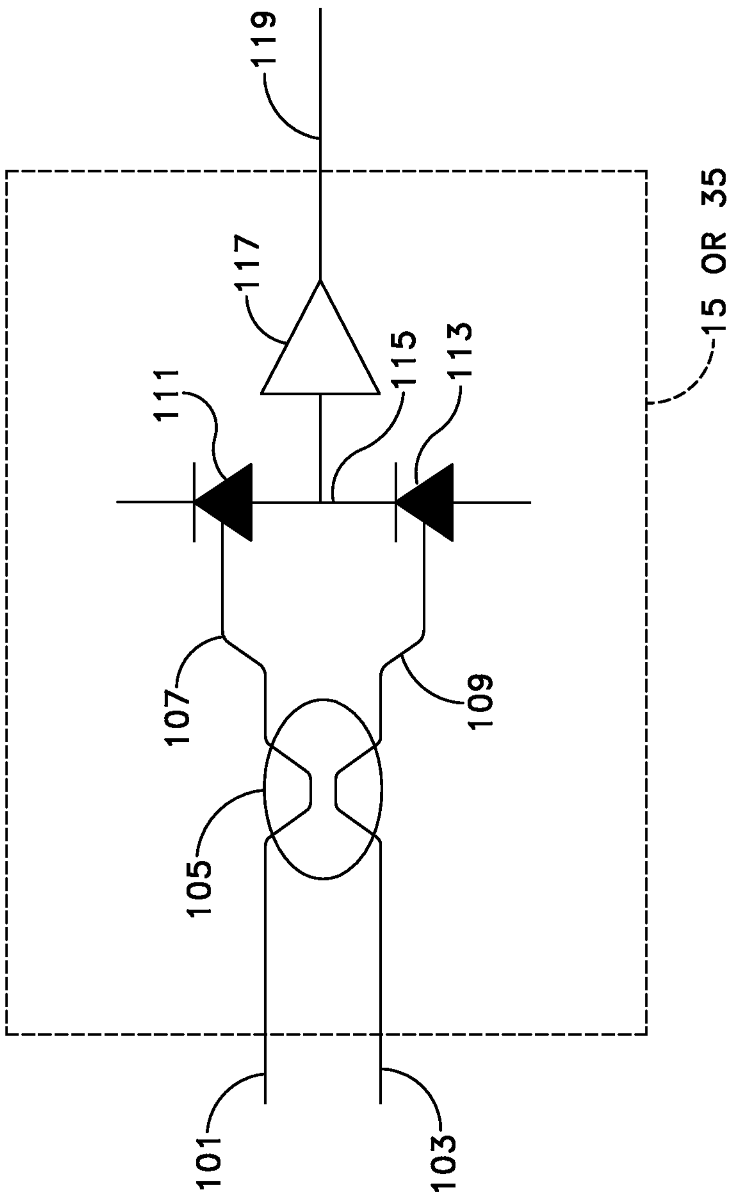

FIG. 4

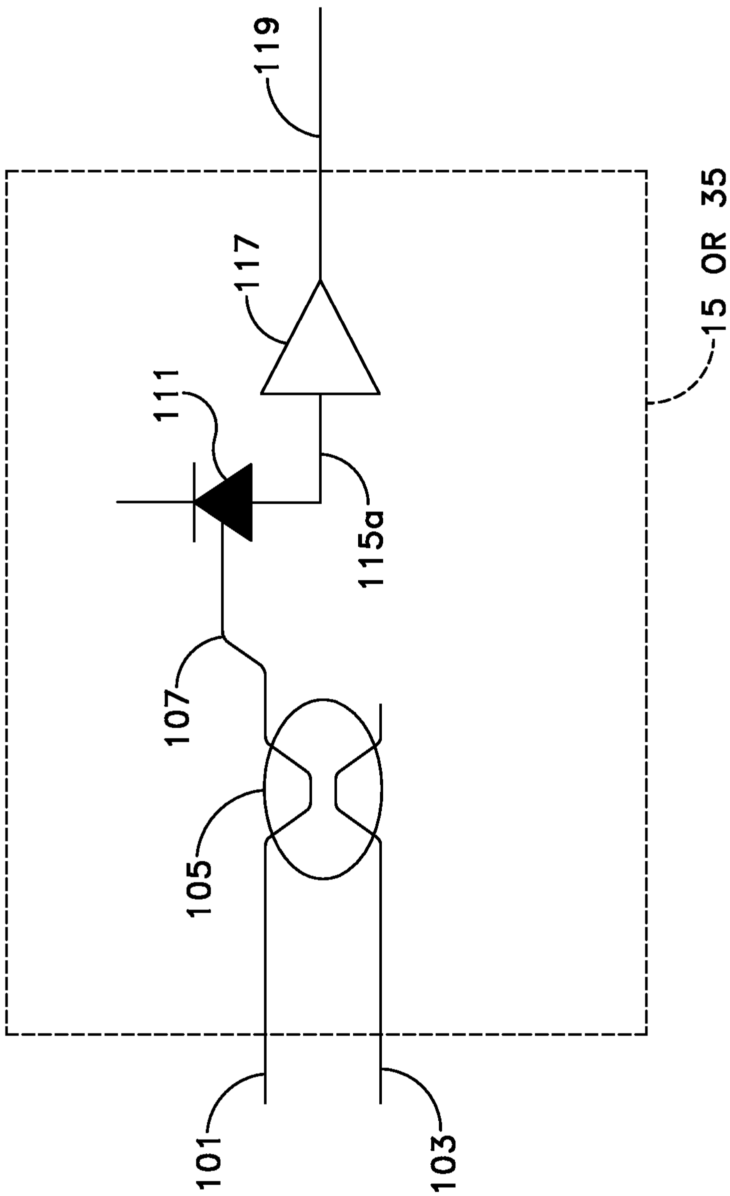

FIG. 5

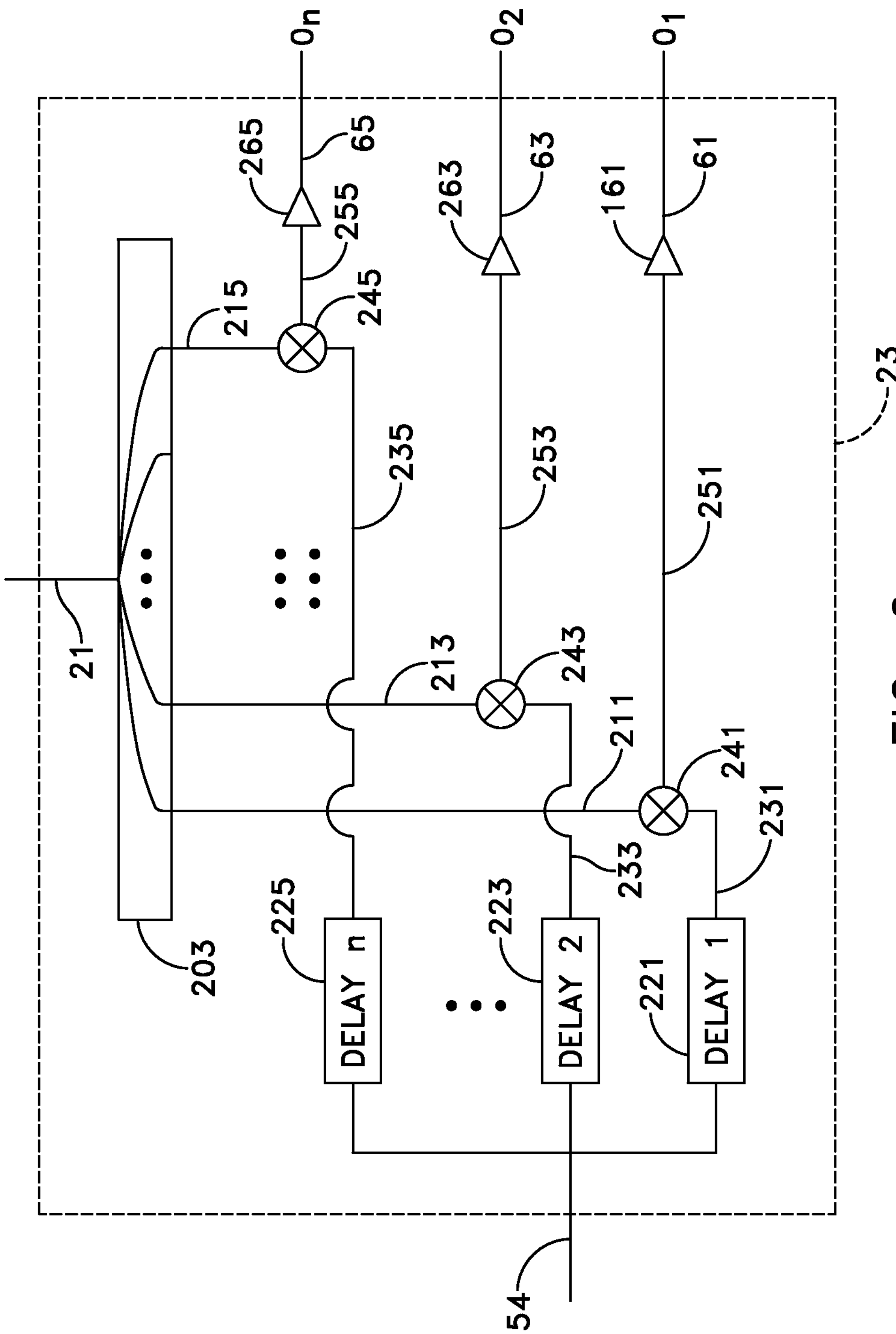
On
O2
O1
265
65
255
263
63
161
61
215
245
235
253
251
23
21
213
243
211
241
231
233
225
223
221
203
DELAY n
DELAY 2
DELAY 1
54

FIG. 6

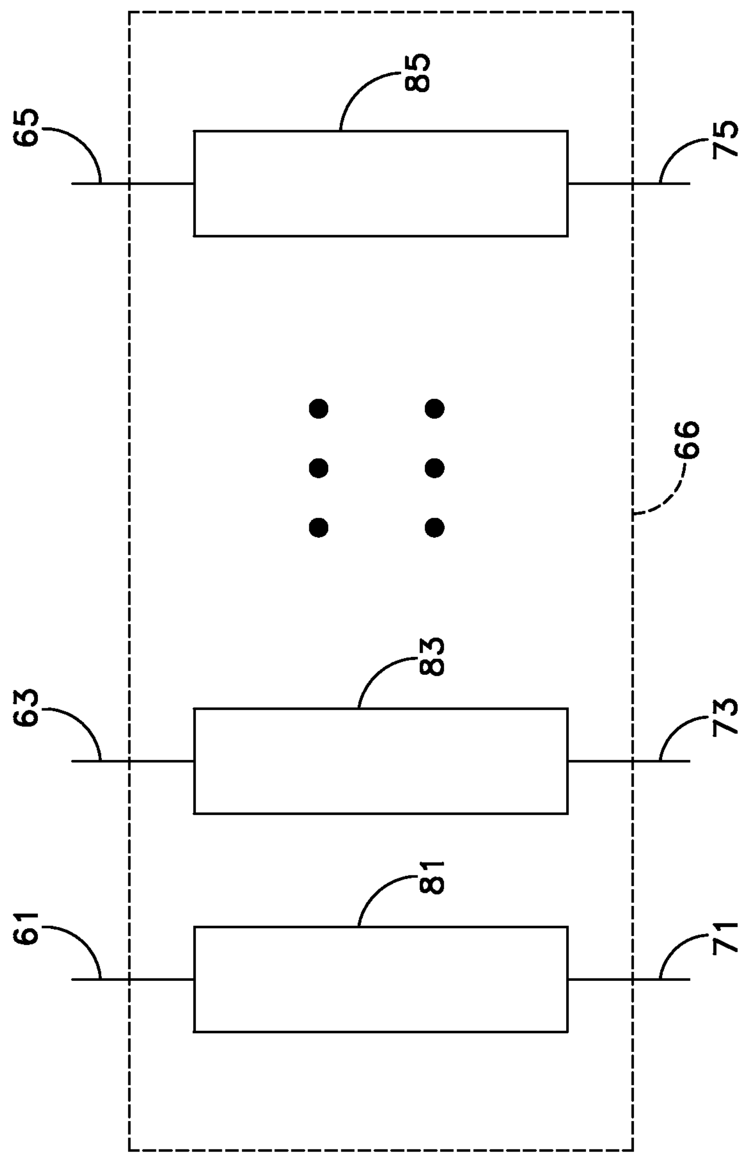

FIG. 7

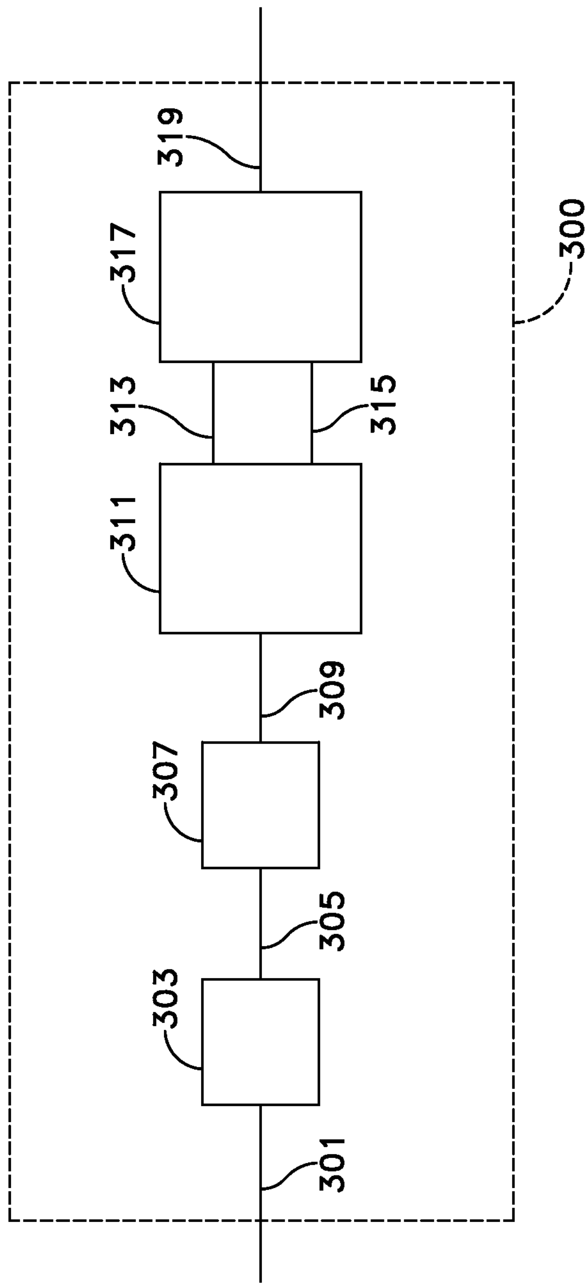

FIG. 8

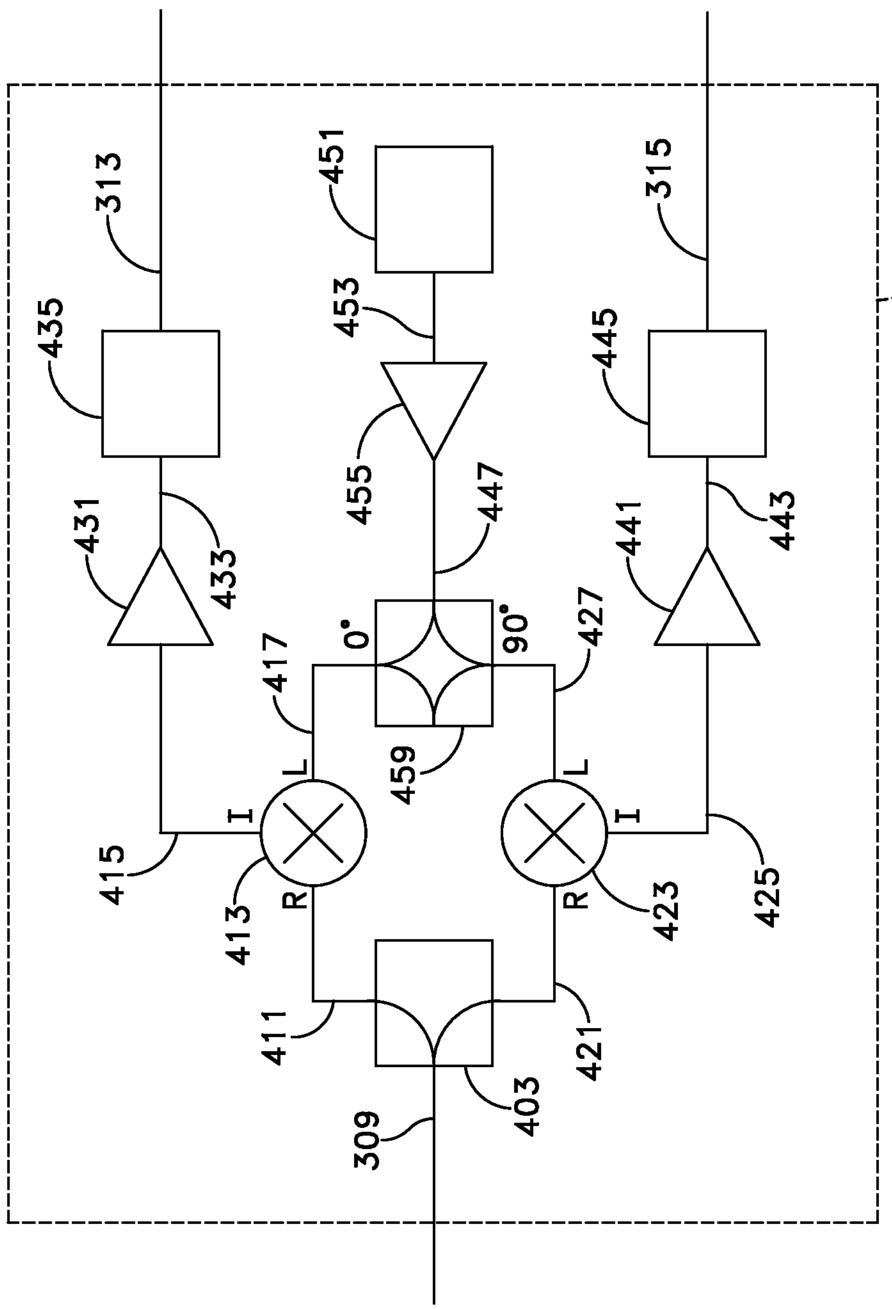
313
451
315
311
435
453
445
455
447
431
433
441
443
0°
90°
417
427
459
L
L
I
I
415
413
R
R
423
425
411
421
403
309

FIG. 9

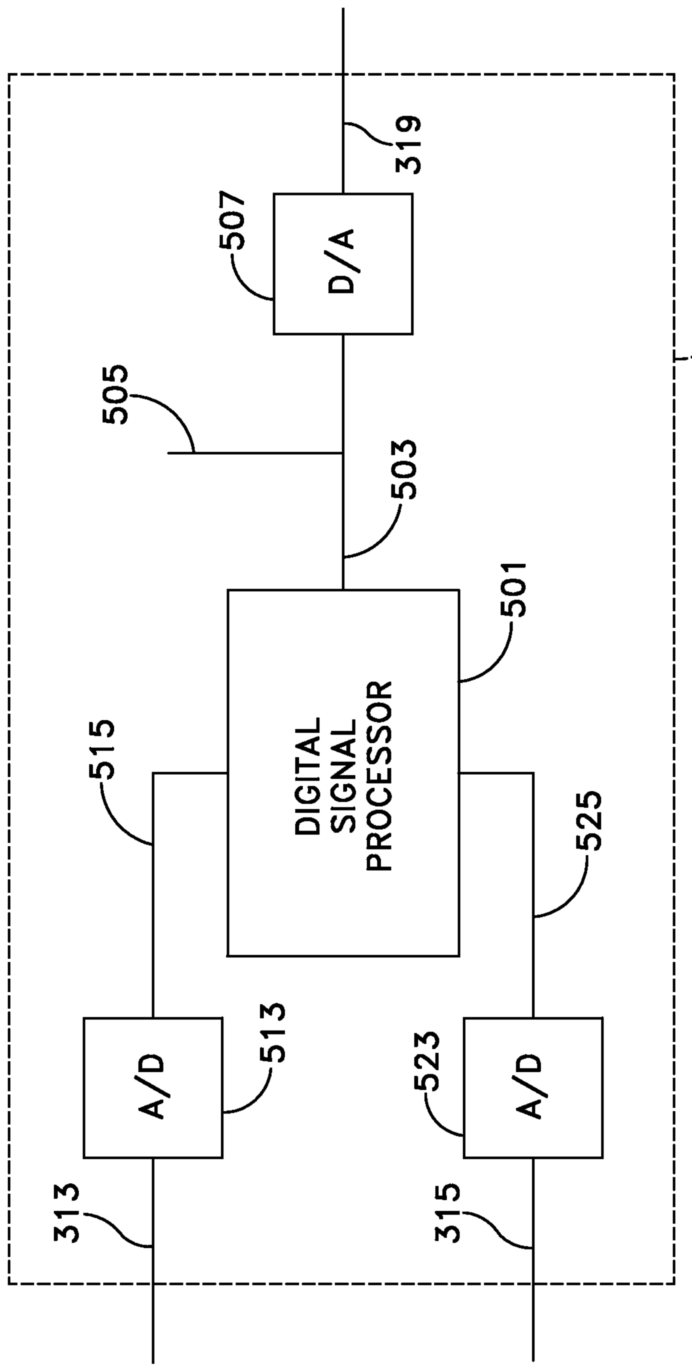
319
507
D/A
317
505
503
501
DIGITAL
SIGNAL
PROCESSOR
515
525
A/D
513
523
A/D
313
315

FIG. 10

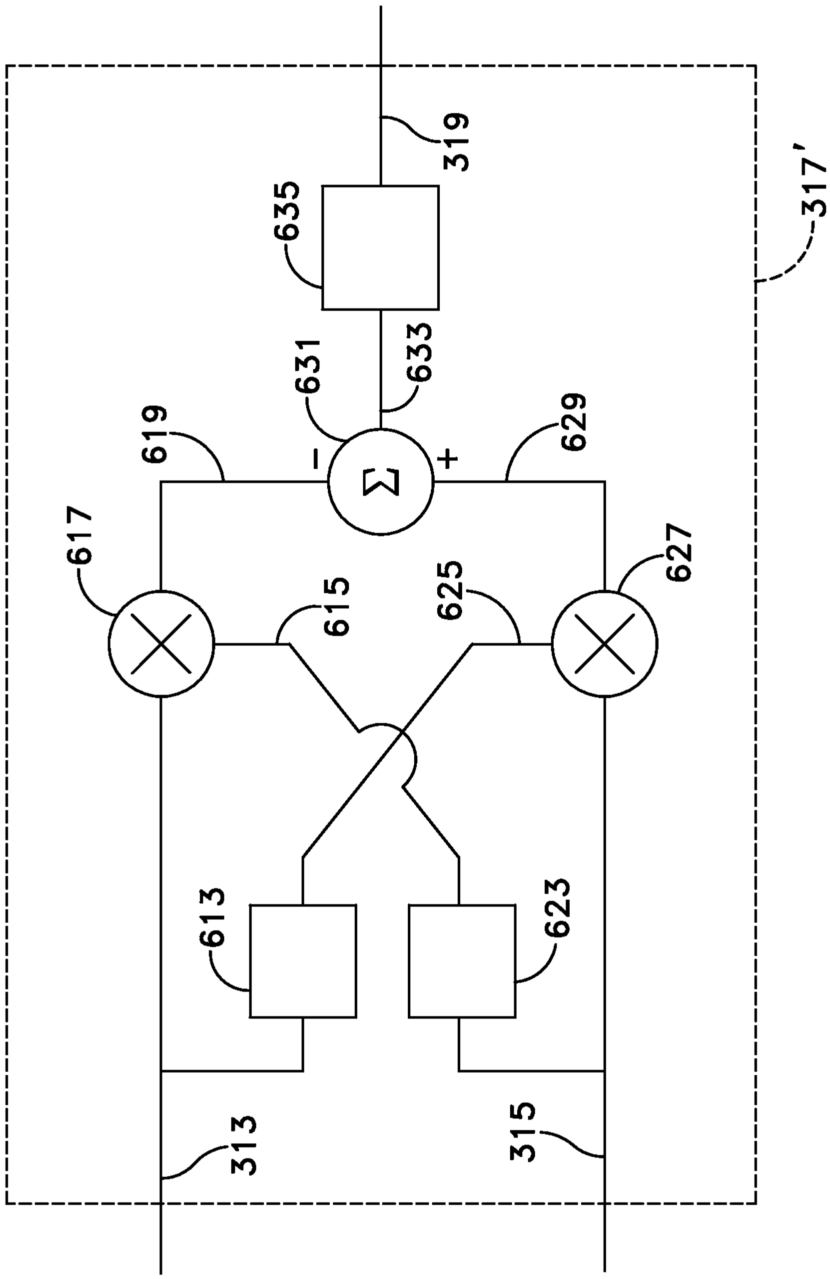

FIG. 11

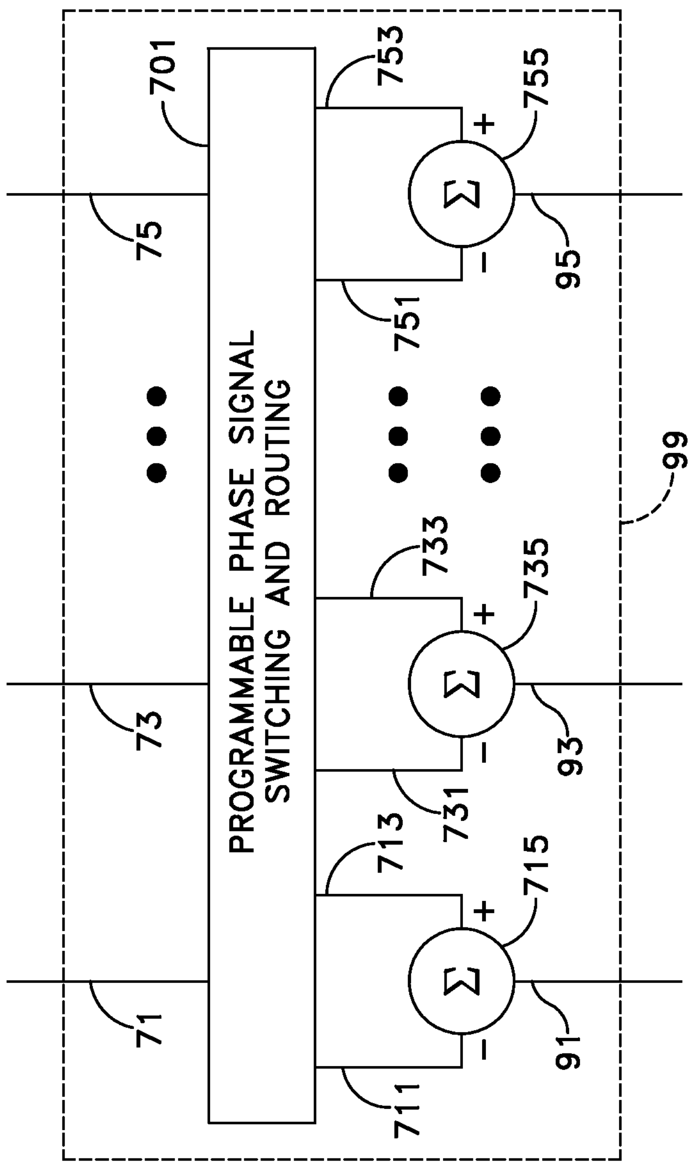
PROGRAMMABLE PHASE SIGNAL
SWITCHING AND ROUTING
701
71
73
75
711
713
715
731
733
735
751
753
755
91
93
95
99

FIG. 12

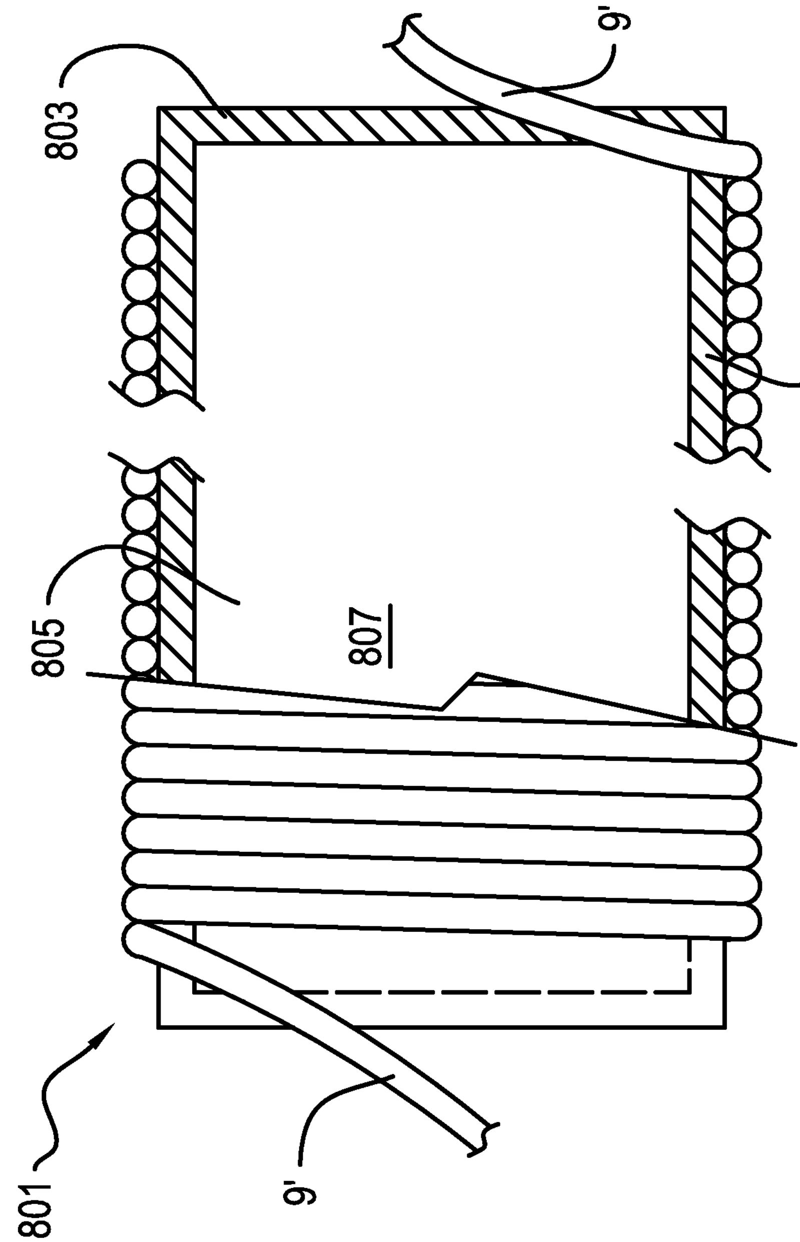

FIG. 13

REISSUE APPLICATION: CONSENT OF ASSIGNEE; STATEMENT OF NON-ASSIGNMENT

Docket Number (Optional)

300099

This is part of the application for a reissue patent based on the original patent identified below.

Name of Patentee(s)

Robert M. Payton

Patent Number	Date Patent Issued
7,030,971	18 April 2006

Title of Invention

Natural Span Reflectometry with Sensing Zone Segments

1. [x] Filed herein is a statement under 37 CFR 3.73(c). (Form PTO/AIA/96)

2. [ ] Ownership of the patent is in the inventor(s), and no assignment of the patent is in effect.

One of boxes 1 or 2 above must be checked. If multiple assignees, complete this form for each assignee. If box 2 is checked, skip the next entry and go directly to "Name of Assignee."

The written consent of all assignees and inventors owning an undivided interest in the original patent is included in this application for reissue.

The assignee(s) owning an undivided interest in said original patent is/are The United States of America, and the assignee(s) consents to the accompanying application for reissue.

Name of assignee/inventor (if not assigned)

The United States of America as represented by the Secretary of the Navy

Signature	Date
James M. Kasischke	16 June 2015

Typed or printed name and title of person signing for assignee (if assigned)

James M. Kasischke

PTO/AIA/96 (08-12)
Approved for use through 01/31/2013. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

STATEMENT UNDER 37 CFR 3.73(c)

Applicant/Patent Owner: The United States of America represented by the Secretary of the Navy

Application No./Patent No.: 7,030,971 Filed/Issue Date: 18 April 2006

Titled: Natural Span Reflectometry with Sensing Zone Segments

The United States of America represented by the Secretary of the Navy, a government agency

(Name of Assignee) (Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)

states that, for the patent application/patent identified above, it is (choose one of options 1, 2, 3 or 4 below):

1. [✓] The assignee of the entire right, title, and interest.

2. [ ] An assignee of less than the entire right, title, and interest (check applicable box):

[ ] The extent (by percentage) of its ownership interest is ____________%. Additional Statement(s) by the owners holding the balance of the interest must be submitted to account for 100% of the ownership interest.

[ ] There are unspecified percentages of ownership. The other parties, including inventors, who together own the entire right, title and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

3. [ ] The assignee of an undivided interest in the entirety (a complete assignment from one of the joint inventors was made). The other parties, including inventors, who together own the entire right, title, and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

4. [ ] The recipient, via a court proceeding or the like (e.g., bankruptcy, probate), of an undivided interest in the entirety (a complete transfer of ownership interest was made). The certified document(s) showing the transfer is attached.

The interest identified in option 1, 2 or 3 above (not option 4) is evidenced by either (choose one of options A or B below):

A. [✓] An assignment from the inventor(s) of the patent application/patent identified above. The assignment was recorded in the United States Patent and Trademark Office at Reel 016024, Frame 0428, or for which a copy thereof is attached.

B. [ ] A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as follows:

1. From: ____________________ To: ____________________

The document was recorded in the United States Patent and Trademark Office at

Reel ____________, Frame ____________, or for which a copy thereof is attached.

2. From: ____________________ To: ____________________

The document was recorded in the United States Patent and Trademark Office at

Reel ____________, Frame ____________, or for which a copy thereof is attached.

STATEMENT UNDER 37 CFR 3.73(c)

3. From: ______________________ To: ______________________

The document was recorded in the United States Patent and Trademark Office at

Reel ________, Frame ________, or for which a copy thereof is attached.

4. From: ______________________ To: ______________________

The document was recorded in the United States Patent and Trademark Office at

Reel ________, Frame ________, or for which a copy thereof is attached.

5. From: ______________________ To: ______________________

The document was recorded in the United States Patent and Trademark Office at

Reel ________, Frame ________, or for which a copy thereof is attached.

6. From: ______________________ To: ______________________

The document was recorded in the United States Patent and Trademark Office at

Reel ________, Frame ________, or for which a copy thereof is attached.

☐ Additional documents in the chain of title are listed on a supplemental sheet(s).

☑ As required by 37 CFR 3.73(c)(1)(i), the documentary evidence of the chain of title from the original owner to the assignee was, or concurrently is being, submitted for recordation pursuant to 37 CFR 3.11.

[NOTE: A separate copy (i.e., a true copy of the original assignment document(s)) must be submitted to Assignment Division in accordance with 37 CFR Part 3, to record the assignment in the records of the USPTO. See MPEP 302.08]

The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

James M. Kasischke (signature)
Signature

14 April 2015
Date

James M. Kasischke
Printed or Typed Name

36562
Title or Registration Number

PTO/AIA/05 (06-12)
Approved for use through 08/31/2013. OMB 0651-0033
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

REISSUE APPLICATION DECLARATION BY THE ASSIGNEE	Docket Number (optional) 300099

I hereby declare that:

The residence and mailing address of the inventor or joint inventors are stated below.

I am authorized to act on behalf of the following assignee: The United States of America as represented by the Secre

The entire title to the patent identified below is vested in said assignee.

Inventor Robert Michael Payton

Residence: City	State	Country
Tomball	TX	USA

Mailing Address
16307 Avenplace Road

City	State	Zip	Country
Tomball	TX	77377	USA

☐ Additional Inventors are named on separately numbered sheets attached hereto.

Patent Number 7,030,971	Date of Patent Issued 18 April 2006

I believe said inventor(s) to be the original inventor or original joint inventors of the subject matter which is described and claimed in said patent, for which a reissue patent is sought on the invention titled:

Natural Span Reflectometry with Sensing Zone Segments

the specification of which

☑ is attached hereto.

☐ was filed on ______________________ as reissue application number ______________.

The above-identified application was made or authorized to be made by me.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

I believe the original patent to be wholly or partly inoperative or invalid, for the reasons described below. (Check all boxes that apply.)

☐ by reason of a defective specification or drawing.

☑ by reason of the patentee claiming more or less than he had the right to claim in the patent.

☐ by reason of other errors.

REISSUE APPLICATION DECLARATION BY THE ASSIGNEE | Docket Number (Optional) 300089

At least one error upon which reissue is based is described below. If the reissue is a broadening reissue, a claim that the application seeks to broaden must be identified and the box below must be checked:

Application failed to claim aspects of the invention related to sensing zone segments on a span optical fiber wherein the zone segments have specialized sensing functions

[Attach additional sheets, if needed.]

☑ **The application for the original patent was filed under 37 CFR 1.46 by the assignee of the entire interest.**

I hereby appoint:

☑ Practitioners associated with Customer Number: 23523

OR

☐ Practitioner(s) named below:

Name	Registration Number

as my/our attorney(s) or agent(s) to prosecute the application identified above, and to transact all business in the United States Patent and Trademark Office connected therewith.

Correspondence Address: Direct all communications about the application to:

☑ The address associated with Customer Number: 23523

OR

☐ Firm or Individual Name					
Address					
City		State		Zip	
Country					
Telephone		Email			

WARNING:

Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.

Signature /James M. Kasischke/ | Date (Optional) 16 June 2015

Full name of person signing (given name, family name) James M. Kasischke, Reg. No. 36562

Address of Assignee Naval Undersea Warfare Center, Division, Newport, 1176 Howell Street, Newport, RI 02841

Electronic Patent Application Fee Transmittal

Application Number:	14686161
Filing Date:	
Title of Invention:	Natural Span Reflectometry with Sensing Zone Segments
First Named Inventor/Applicant Name:	Robert M Payton
Filer:	James Martin Kasischke/annette campbell
Attorney Docket Number:	300099

Filed as Large Entity

Filing Fees for **Utility under 35 USC 111(a)**

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Late Filing Fee for Oath or Declaration	1051	1	140	140
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		**140**

Electronic Acknowledgement Receipt

EFS ID:	22641624
Application Number:	14686161
International Application Number:	
Confirmation Number:	5544
Title of Invention:	Natural Span Reflectometry with Sensing Zone Segments
First Named Inventor/Applicant Name:	Robert M Payton
Customer Number:	23523
Filer:	James Martin Kasischke
Filer Authorized By:	
Attorney Docket Number:	300099
Receipt Date:	16-JUN-2015
Filing Date:	
Time Stamp:	13:28:58
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	$140
RAM confirmation Number	11727
Deposit Account	140590
Authorized User	KASISCHKE, JAMES M

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Applicant Response to Pre-Exam Formalities Notice	300099responsetopreexam.pdf	4131813 7ae988786ab9ac1a96cdee105db8bafe0f34e02f	no	53

Warnings:

The page size in the PDF is too large. The pages should be 8.5 x 11 or A4. If this PDF is submitted, the pages will be resized upon entry into the Image File Wrapper and may affect subsequent processing

Information:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
2	Fee Worksheet (SB06)	fee-info.pdf	30209 5815a1d6bd41e9ddbb21b773d7aa85d8236abebb	no	2

Warnings:

Information:

Total Files Size (in bytes): 4162022

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number
14/686,161

APPLICATION AS FILED - PART I

FOR	NUMBER FILED (Column 1)	NUMBER EXTRA (Column 2)	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A			N/A	280
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A			N/A	600
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	2160
TOTAL CLAIMS (37 CFR 1.16(i))	16 minus 20 =	*			OR	x 80 =	0.00
INDEPENDENT CLAIMS (37 CFR 1.16(h))	2 minus 3 =	*				x 420 =	0.00
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).						0.00
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))							0.00
			TOTAL			TOTAL	3040

* If the difference in column 1 is less than zero, enter "0" in column 2.

APPLICATION AS AMENDED - PART II

AMENDMENT A

	CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
Application Size Fee (37 CFR 1.16(s))									
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
					TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

AMENDMENT B

	CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
Application Size Fee (37 CFR 1.16(s))									
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
					TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
14/686,161	04/14/2015	Robert M Payton	300099

CONFIRMATION NO. 5544

FORMALITIES LETTER

OC000000074665258

23523
NAVAL UNDERSEA WARFARE CENTER
DIVISION NEWPORT
1176 HOWELL STREET, Code 00L
Bldg. 102T
NEWPORT, RI 02841

Date Mailed: 04/16/2015

NOTICE OF INCOMPLETE REISSUE APPLICATION

FILED UNDER 37 CFR 1.53(b)

A filing date has NOT been accorded to the above identified application papers for the reason(s) indicated below.

All of the items noted below **and a newly executed oath or declaration covering the items must** be submitted within **TWO MONTHS** of the date of this Notice, unless otherwise indicated, or proceedings on the application will be terminated *(37 CFR 1.53(e))*.

The filing date will be the date of receipt of all items required below, unless otherwise indicated. Any assertions that the item(s) required below were submitted, or are not necessary for a filing date, must be by way of petition directed to the attention of the Office of Petitions accompanied by the $130.00 petition fee *(37 CFR 1.17(h))*. If the petition states that the application is entitled to a filing date, a request for a refund of the petition fee may be included in the petition.

- The specification is missing.
  A complete specification as prescribed by 35 U.S.C. 112 is required.

The required items noted below SHOULD be filed along with any items required above. The filing date of this reissue application will be the date of receipt of the items required above.

- The application was deposited without drawings. 35 U.S.C. 113 (first sentence) requires a drawing "where necessary for the understanding of the subject matter sought to be patented."
  Applicant should reconsider whether the drawings are necessary under 35 U.S.C. 113 (first sentence).
- Consent of assignee is missing. 37 CFR 1.172 requires that a reissue oath/declaration be accompanied by the written consent of all assignees.

Replies should be mailed to:

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web, including a copy of this Notice and selecting the document description "Applicant response to Pre-Exam Formalities Notice". https://sportal.uspto.gov/authenticate/AuthenticateUserLocalEPF.html

For more information about EFS-Web please call the USPTO Electronic Business Center at **1-866-217-9197** or visit our website at http://www.uspto.gov/ebc.

If you are not using EFS-Web to submit your reply, you must include a copy of this notice.

/vostuart/

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

PTO/AIA/50 (09-14)
Approved for use through 10/31/2016. OMB 0651-0033
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

REISSUE PATENT APPLICATION TRANSMITTAL

Address to:

Mail Stop Reissue
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Attorney Docket No.	300099
First Named Inventor	Robert M. Payton
Original Patent Number	7,030,971
Original Patent Issue Date (Month/Day/Year)	04/18/2006
Express Mail Label No.	

APPLICATION FOR REISSUE OF:
(Check applicable box) [✓] Utility Patent [ ] Design Patent [ ] Plant Patent

APPLICATION ELEMENTS (37 CFR 1.173)

1. [✓] **Fee Transmittal Form** (PTO/SB/56)
2. [ ] **Applicant asserts small entity status.** See 37 CFR 1.27
3. [ ] **Applicant certifies micro entity status.** See 37 CFR 1.29. Applicant must attach form PTO/SB/15A or B or equivalent.
4. [✓] **Specification and Claims** in double column copy of patent format *(amended, if appropriate)*
5. [ ] **Drawing(s)** *(proposed amendments, if appropriate)*
6. [✓] **Reissue Oath/Declaration or Substitute Statement** (37 CFR 1.175) (PTO/AIA/05, 06, or 07)
7. [✓] **Application Data Sheet** NOTE: Benefit claims under 37 CFR 1.78 and foreign priority claims under 37 CFR 1.55 MUST be set forth in an Application Data Sheet (ADS).
8. [✓] **Original U.S. Patent currently assigned?** [✓] Yes [ ] No *(If Yes, check applicable box(es))*
   - [ ] Written Consent of all Assignees (PTO/AIA/53)
   - [✓] 37 CFR 3.73(c) Statement (PTO/AIA/96)
9. [ ] **CD-ROM or CD-R** in duplicate, Computer Program *(Appendix)* or large table
   - [ ] Landscape Table on CD
10. **Nucleotide and/or Amino Acid Sequence Submission** *(if applicable, items a. – c. are required)*
    - a. [ ] Computer Readable Form (CRF)
    - b. [ ] Specification Sequence Listing on:
      - i. [ ] CD-ROM (2 copies) or CD-R (2 copies); or
      - ii. [ ] Paper
    - c. [ ] Statements verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

11. [✓] **Statement of status and support for all changes to the claims.** See 37 CFR 1.173(c).
12. [ ] **Power of Attorney**
13. [ ] **Information Disclosure Statement (IDS)** PTO/SB/08 or PTO-1449
    - [ ] Copies of citations attached
14. [ ] **English translation of Reissue Oath/Declaration** *(if applicable)*
15. [ ] **Return Receipt Postcard** (MPEP § 503) (Should be specifically itemized)
16. [✓] **Preliminary Amendment** (37 CFR 1.173; MPEP § 1453)
17. [ ] **Other:** ______

[ ] This is a continuation reissue or divisional reissue application *(i.e., a second or subsequent reissue application for the same issued patent). (Check box if applicable.)*

18. CORRESPONDENCE ADDRESS

[✓] The address associated with Customer Number: 23523 **OR** [ ] Correspondence address below

Name					
Address					
City		State		Zip Code	
Country		Telephone			
Email					

Signature	/James M. Kasischke/ (signed)	Date	14 April 2015
Name (Print/Type)	James M. Kasischke	Registration No.	36562

PTO/SB/56 (03-13)
Approved for use through 08/31/2013. OMB 0651-0033
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Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

REISSUE APPLICATION FEE TRANSMITTAL FORM

Docket Number (Optional): 300099

Application as Filed – Part 1

	(1) Claims in Patent	(2) Claims Filed in Reissue Application	(3) Number Extra	Micro Entity Rate ($)	Micro Entity Fee ($)	Small Entity Rate ($)	Small Entity Fee ($)	Undiscounted Rate ($)	Undiscounted Fee ($)
Total Claims (37 CFR 1.16(i))	(A) 22	(B) 16	* =	x =		x =		x =	
Ind. Claims (37 CFR 1.16(h))	(C) 3	(D) 2	** =	x =		x =		x =	
Application Size Fee (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $400 ($200 for small entity, $100 for micro entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).								
		Filing Fee (37 CFR 1.16(e))							280.00
		Search Fee (37 CFR 1.16(n))							600.00
		Examination Fee (37 CFR 1.16(r))							2160.00
		Total Filing Fee							3040.00

Application as Amended – Part 2

	(1) Claims Remaining After Amendment	(2) Highest Number Previously Paid For	(3) Extra Claims Present	Micro Entity Rate ($)	Micro Entity Fee ($)	Small Entity Rate ($)	Small Entity Fee ($)	Undiscounted Rate ($)	Undiscounted Fee ($)
Total Claims (37 CFR 1.16(i))	*** 16 -	**** 20	=	x =		x =		x =	
Ind. Claims (37 CFR 1.16(h))	*** 2 -	***** 3	=	x =		x =		x =	
Application Size Fee (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $400 ($200 for small entity, $100 for micro entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).								
			Total Additional Fee						

* Enter (B) – 20, or enter "0" if (B) is less than 20.
** Enter (D) – minus 3, or enter "0" if (D) is less than 3.
*** After any cancellation of claims.
**** If the "Highest Number of Total Claims Previously Paid For" is less than 20, enter "20" in this space.
***** If the "Highest Number of Independent Claims Previously Paid For" is less than 3, enter "3" in this space.

- [ ] Applicant asserts small entity status. See 37 CFR 1.27.
- [ ] Applicant certifies micro entity status. See 37 CFR 1.29.
  Form PTO/SB/15A or B or equivalent must either be enclosed or have been submitted previously.
- [x] The Director is hereby authorized to charge any additional fees under 37 CFR 1.16 or 1.17 which may be required, or credit any overpayment to Deposit Account No. 14-0590.
- [ ] A check in the amount of $ __________ to cover the filing/additional fee is enclosed.
- [ ] Payment made via EFS-Web.
- [ ] Payment by credit card. Form PTO-2038 is attached. WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

/James M. Kasischke/ (signature) — Signature
19 April 2015 — Date

James M. Kasischke — Typed or Printed Name
36562 — Registration Number, if applicable
401-832-3653 — Telephone Number

PTO/AIA/08 (06-12)
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REISSUE APPLICATION DECLARATION BY THE ASSIGNEE	Docket Number (optional) 300099

I hereby declare that:

The residence and mailing address of the inventor or joint inventors are stated below.

I am authorized to act on behalf of the following assignee: The United States of America as represented by the Secre

The entire title to the patent identified below is vested in said assignee.

Inventor Robert Michael Payton

Residence: City	State	Country
Tomball	TX	USA

Mailing Address
11623 Trail Point Drive

City	State	Zip	Country
Tomball	TX	77377	USA

☐ Additional inventors are named on separately numbered sheets attached hereto.

Patent Number 7,030,971	Date of Patent Issued 18 April 2006

I believe said inventor(s) to be the original inventor or original joint inventors of the subject matter which is described and claimed in said patent, for which a reissue patent is sought on the invention titled:

Natural Span Reflectometry with Sensing Zone Segments

the specification of which

☑ is attached hereto.

☐ was filed on ______________ as reissue application number ______________.

The above-identified application was made or authorized to be made by me.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

I believe the original patent to be wholly or partly inoperative or invalid, for the reasons described below. (Check all boxes that apply.)

☐ by reason of a defective specification or drawing.

☑ by reason of the patentee claiming more or less than he had the right to claim in the patent.

☐ by reason of other errors.

REISSUE APPLICATION DECLARATION BY THE ASSIGNEE

Docket Number (Optional) 300099

At least one error upon which reissue is based is described below. If the reissue is a broadening reissue, a claim that the application seeks to broaden must be identified and the box below must be checked:

Applicant failed to claim aspects of the invention related to sensing zone segments on a span of optical fiber wherein the zone segments have specialized sensing functions.

[Attach additional sheets, if needed.]

☑ **The application for the original patent was filed under 37 CFR 1.46 by the assignee of the entire interest.**

I hereby appoint:

☑ Practitioners associated with Customer Number: 23523

OR

☐ Practitioner(s) named below:

Name	Registration Number

as my/our attorney(s) or agent(s) to prosecute the application identified above, and to transact all business in the United States Patent and Trademark Office connected therewith.

Correspondence Address: Direct all communications about the application to:

☑ The address associated with Customer Number: 23523

OR

☐ Firm or Individual Name	
Address	
City	State: Zip:
Country	
Telephone	Email:

WARNING:

Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.

Signature: James M. Kasischke (signed) | Date (Optional):

Full name of person signing (given name, family name): James M. Kasischke, Reg. No. 36562

Address of Assignee: Naval Undersea Warfare Center, Division, Newport, 1176 Howell Street, Newport, RI 02841

Doc Code: REIS.DECL
Document Description: Reissue Declaration Filed In Accordance With MPEP 1414

PTO/AIA/05 (06-12)
Approved for use through 08/31/2013. OMB 0651-0033
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REISSUE APPLICATION DECLARATION BY THE INVENTOR	Docket Number (Optional) 300099

I hereby declare that:
Each inventor's residence and mailing address are stated below next to their name.
I believe I am the original inventor or an original joint inventor of the subject matter which is described and claimed in patent number 7,030,971, granted 18 April 2006 and for which a reissue patent is sought on the invention titled Natural Span Reflectometry with Sensing Zone Segments,

the specification of which

☑ is attached hereto.

☐ was filed on ______________ as reissue application number ______________.

The above-identified application was made or authorized to be made by me.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

I believe the original patent to be wholly or partly inoperative or invalid, for the reasons described below. (Check all boxes that apply.)

☐ by reason of a defective specification or drawing.

☑ by reason of the patentee claiming more or less than he had the right to claim in the patent.

☐ by reason of other errors.

At least one error upon which reissue is based is described below. If the reissue is a broadening reissue, a claim that the application seeks to broaden must be identified:

Applicant failed to claim aspects of the invention related to sensing zone segments on a span of optical fiber wherein the zone segments have specialized sensing functions.

(REISSUE APPLICATION DECLARATION BY THE INVENTOR, page 2)

Docket Number (Optional): 300099

Note: To appoint a power of attorney, use form PTO/AIA/81.

Correspondence Address: Direct all communications about the application to:

☑ The address associated with Customer Number: 23523

OR

☐ Firm or Individual Name					
Address					
City		State		Zip	
Country					
Telephone			Email		

WARNING:

Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.

Legal name of sole or first inventor (*E.g.*, Given Name (first and middle (if any) and Family Name or Surname)
Robert Michael Payton

Inventor's Signature		Date (Optional)	
[signature]		08 April 2015	
Residence: City: Tomball	State: TX	Country: USA	
Mailing Address: 11623 Trail Point Drive			
City: Tomball	State: TX	Zip: 77377-1349	Country: USA

☐ Additional joint inventors are named on the ______ supplemental sheet(s) PTO/AIA/10 attached hereto.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	300099
	Application Number	
Title of Invention	Natural Span Reflectometry with Sensing Zone Segments	

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.

Secrecy Order 37 CFR 5.2

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Inventor Information:

Inventor 1 [Remove]

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Robert	M	Payton	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

City	Tomball	State/Province	TX	Country of Residence i	US

Mailing Address of Inventor:

Address 1	11623 Trail Point Drive		
Address 2			
City	Tomball	State/Province	TX
Postal Code	77377	Country i	US

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. [Add]

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below. For further information see 37 CFR 1.33(a).

☐ **An Address is being provided for the correspondence Information of this application.**

Customer Number	23523
Email Address	[Add Email] [Remove Email]

Application Information:

Title of the Invention	Natural Span Reflectometry with Sensing Zone Segments		
Attorney Docket Number	300099	Small Entity Status Claimed	☐
Application Type	Nonprovisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)		Suggested Figure for Publication (if any)	

Filing By Reference :

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	300099
	Application Number	
Title of Invention	Natural Span Reflectometry with Sensing Zone Segments	

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country i

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32).
Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Please Select One:	◉ Customer Number	○ US Patent Practitioner	○ Limited Recognition (37 CFR 11.9)
Customer Number	23523		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, or 365(c) or indicate National Stage entry from a PCT application. Providing this information in the application data sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.
When referring to the current application, please leave the application number blank.

Prior Application Status		Remove	
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button. Add

Foreign Priority Information:

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	300099
	Application Number	

Title of Invention	Natural Span Reflectometry with Sensing Zone Segments

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55(d). When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX) i the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(h)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

Remove

Application Number	Country i	Filing Date (YYYY-MM-DD)	Access Code i (if applicable)

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button. Add

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.
NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

Authorization to Permit Access:

☐ Authorization to Permit Access to the Instant Application by the Participating Offices

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	300099
	Application Number	

Title of Invention	Natural Span Reflectometry with Sensing Zone Segments

If checked, the undersigned hereby grants the USPTO authority to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the World Intellectual Property Office (WIPO), and any other intellectual property offices in which a foreign application claiming priority to the instant patent application is filed access to the instant patent application. See 37 CFR 1.14(c) and (h). This box should not be checked if the applicant does not wish the EPO, JPO, KIPO, WIPO, or other intellectual property office in which a foreign application claiming priority to the instant patent application is filed to have access to the instant patent application.

In accordance with 37 CFR 1.14(h)(3), access will be provided to a copy of the instant patent application with respect to: 1) the instant patent application-as-filed; 2) any foreign application to which the instant patent application claims priority under 35 U.S.C. 119(a)-(d) if a copy of the foreign application that satisfies the certified copy requirement of 37 CFR 1.55 has been filed in the instant patent application; and 3) any U.S. application-as-filed from which benefit is sought in the instant patent application.

In accordance with 37 CFR 1.14(c), access may be provided to information concerning the date of filing this Authorization.

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1 Remove

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

Clear

- ○ Assignee
- ○ Legal Representative under 35 U.S.C. 117
- ○ Joint Inventor
- ◉ Person to whom the inventor is obligated to assign.
- ○ Person who shows sufficient proprietary interest

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor :

If the Applicant is an Organization check here. ☐

Prefix	**Given Name**	Middle Name	**Family Name**	Suffix

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	300099
	Application Number	

Title of Invention	Natural Span Reflectometry with Sensing Zone Segments

Mailing Address Information:			
Address 1			
Address 2			
City		**State/Province**	
Country i		Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Applicant Data may be generated within this form by selecting the Add button. Add

Assignee Information including Non-Applicant Assignee Information:

Providing assignment information in this section does not subsitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Assignee 1

Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication . An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.

Remove

If the Assignee or Non-Applicant Assignee is an Organization check here. ☐

Prefix	**Given Name**	Middle Name	**Family Name**	Suffix

Mailing Address Information For Assignee including Non-Applicant Assignee:			
Address 1			
Address 2			
City		**State/Province**	
Country i		Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button. Add

PTO/AIA/14 (12-13)
Approved for use through 01/31/2014. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	300099
	Application Number	
Title of Invention	Natural Span Reflectometry with Sensing Zone Segments	

Signature:

Remove

NOTE: This form must be signed in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications

Signature	/James M. Kasischke/			Date (YYYY-MM-DD)	2015-04-14
First Name	James	Last Name	Kasischke	Registration Number	36562

Additional Signature may be generated within this form by selecting the Add button. Add

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these records.

2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.

3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.

4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).

5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.

6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).

7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.

8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspections or an issued patent.

9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

STATEMENT UNDER 37 CFR 3.73(c)

Applicant/Patent Owner: The United States of America represented by the Secretary of the Navy

Application No./Patent No.: 7,030,971 Filed/Issue Date: 18 April 2006

Titled: Natural Span Reflectometry with Sensing Zone Segments

The United States of America represented by the Secretary of the Navy, a government agency

(Name of Assignee) (Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)

states that, for the patent application/patent identified above, it is (choose one of options 1, 2, 3 or 4 below):

1. ☑ The assignee of the entire right, title, and interest.

2. ☐ An assignee of less than the entire right, title, and interest (check applicable box):

☐ The extent (by percentage) of its ownership interest is ________%. Additional Statement(s) by the owners holding the balance of the interest must be submitted to account for 100% of the ownership interest.

☐ There are unspecified percentages of ownership. The other parties, including inventors, who together own the entire right, title and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

3. ☐ The assignee of an undivided interest in the entirety (a complete assignment from one of the joint inventors was made). The other parties, including inventors, who together own the entire right, title, and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

4. ☐ The recipient, via a court proceeding or the like (*e.g.*, bankruptcy, probate), of an undivided interest in the entirety (a complete transfer of ownership interest was made). The certified document(s) showing the transfer is attached.

The interest identified in option 1, 2 or 3 above (not option 4) is evidenced by either (choose one of options A or B below):

A. ☑ An assignment from the inventor(s) of the patent application/patent identified above. The assignment was recorded in the United States Patent and Trademark Office at Reel 016024, Frame 0426, or for which a copy thereof is attached.

B. ☐ A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as follows:

1. From: ________ To: ________
The document was recorded in the United States Patent and Trademark Office at
Reel ______, Frame ______, or for which a copy thereof is attached.

2. From: ________ To: ________
The document was recorded in the United States Patent and Trademark Office at
Reel ______, Frame ______, or for which a copy thereof is attached.

STATEMENT UNDER 37 CFR 3.73(c)

3. From: ______________________ To: ______________________

The document was recorded in the United States Patent and Trademark Office at

Reel __________, Frame __________, or for which a copy thereof is attached.

4. From: ______________________ To: ______________________

The document was recorded in the United States Patent and Trademark Office at

Reel __________, Frame __________, or for which a copy thereof is attached.

5. From: ______________________ To: ______________________

The document was recorded in the United States Patent and Trademark Office at

Reel __________, Frame __________, or for which a copy thereof is attached.

6. From: ______________________ To: ______________________

The document was recorded in the United States Patent and Trademark Office at

Reel __________, Frame __________, or for which a copy thereof is attached.

☐ Additional documents in the chain of title are listed on a supplemental sheet(s).

☑ As required by 37 CFR 3.73(c)(1)(i), the documentary evidence of the chain of title from the original owner to the assignee was, or concurrently is being, submitted for recordation pursuant to 37 CFR 3.11.

[NOTE: A separate copy (i.e., a true copy of the original assignment document(s)) must be submitted to Assignment Division in accordance with 37 CFR Part 3, to record the assignment in the records of the USPTO. See MPEP 302.08]

The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

James M. Kasischke (signature) — Signature

14 April 2015 — Date

James M. Kasischke — Printed or Typed Name

36562 — Title or Registration Number

Electronic Patent Application Fee Transmittal

Application Number:	
Filing Date:	
Title of Invention:	Natural Span Reflectometry with Sensing Zone Segments
First Named Inventor/Applicant Name:	Robert M Payton
Filer:	James Martin Kasischke/annette campbell
Attorney Docket Number:	300099

Filed as Large Entity

Filing Fees for **Reissue (Utility)**

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Utility Reissue Basic	1014	1	280	280
Design and Utility Reissue Basic	1114	1	600	600
Design and utility Reissue Basic	1314	1	2160	2160
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		**3040**

Electronic Acknowledgement Receipt

EFS ID:	22057486
Application Number:	14686161
International Application Number:	
Confirmation Number:	5544
Title of Invention:	Natural Span Reflectometry with Sensing Zone Segments
First Named Inventor/Applicant Name:	Robert M Payton
Customer Number:	23523
Filer:	James Martin Kasischke
Filer Authorized By:	
Attorney Docket Number:	300099
Receipt Date:	14-APR-2015
Filing Date:	
Time Stamp:	15:44:39
Application Type:	Reissue (Utility)

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	$3040
RAM confirmation Number	2227
Deposit Account	140590
Authorized User	

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Preliminary Amendment	300099PreAm.pdf	166715 d2cc3b5410e8f90df91493e15f0e61d4325e5655	no	10

Warnings:

Information:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
2	Transmittal Reissue Application	300099PATransmittal.pdf	343644 d220122efd0001a57b0d6c5e22422ecb212ce83b	no	1

Warnings:

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Information:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
3	Transmittal Reissue Application	300099applictransform.pdf	346234 1d0fe18054c40e83b9eb2843d6e55bdc3e9e6a6a	no	1

Warnings:

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Information:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
4	Reissue dec filed in accordance with MPEP 1414	300099decbyassignee.pdf	662029 3de99db562538877d27ae5fb8504398849a39e99	no	2

Warnings:

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Information:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
5	Reissue dec filed in accordance with MPEP 1414	300099decbyinventor.pdf	574279 d99ac3caac5f4b6f52ae2104899964cdffad731c	no	2

Warnings:

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Information:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
6	Application Data Sheet	ADS.pdf	1560926 d036da143ba08922c81903c8b746491bce8ad5f3	no	7

Warnings:

Information:

7	Assignee showing of ownership per 37 CFR 3.73	300099cfr373.pdf	585957 4ca99cb83d9a08fed15d4667a5a3c4f26c6179f7	no	2
Warnings:					
The page size in the PDF is too large. The pages should be 8.5 x 11 or A4. If this PDF is submitted, the pages will be resized upon entry into the Image File Wrapper and may affect subsequent processing					
Information:					
8	Fee Worksheet (SB06)	fee-info.pdf	34951 23eb3e2fd9b0a5aff535f2be69278f208fff7557	no	2
Warnings:					
Information:					
			Total Files Size (in bytes):	4274735	

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

Customer No. 23523 14 April 2015

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants: ROBERT MICHAEL PAYTON Orig. Patent No.: 7,030,971
Serial No.: 11/056,630 Orig. Issue Date: 18 Apr 2006
Filed: 7 February 2005 Attorney Docket No. 300099
For: **NATURAL SPAN REFLECTOMETRY WITH SENSING ZONE SEGMENTS**

PRELIMINARY AMENDMENT

Mail Stop Reissue
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

This Preliminary Amendment is being filed with a continuing patent application of reissue patent application.

Amendments to the Specification: are reflected in the substitute paragraph provided on page 2 of this paper.

Amendments to the Abstract: is reflected in the substitute paragraph provided on page 4 of this paper.

Amendments to the Claims: are reflected in the listing of claims which begins on page 5 of this paper.

Amendments to the Drawings: None.

Remarks: begin on page 10 of this paper.

AMENDMENTS TO THE SPECIFICATION

Replace the title of the application at column 1, line 1, as follows: ~~NATURAL FIBER SPAN REFLECTOMETER PROVIDING A VIRTUAL SIGNAL SENSING ARRAY CAPABLITY~~ NATURAL SPAN REFLECTOMETRY WITH SENSING ZONE SEGMENTS.

Insert the following paragraph at column 1, line 3, following the title of the application, prior to the STATEMENT OF GOVERNMENT INTEREST:

This application is a continuation of reissue Application Ser. No. 14/190,478, filed February 16, 2014, which is a reissue of ~~U.S. Patent Application No. 11/056,630 filed February 7, 2005, now~~ U.S. Patent No. 7,030,971 that claims the benefit of a provisional application, No. 60/599,437 which was filed on 6 August 2004, and which is entitled "Continuous Rayleigh Effect Sensor Backscattering Heterodyne Optical Sensor System" by Robert M. Payton.

At column 33, lines 10-37, replace the paragraph as follows:

The details, materials, ~~step~~ steps of operation and arrangement of parts herein have been described and illustrated in order to explain the nature of the invention. Many modifications in these are possible by those skilled in the art within the teachings herein of the invention. For example, while in system 2 the transformation from optical to r.f. signal takes place prior to processing by programmable correlation 23, it is within the skill of the art to design optical receiver 15 and correlator system 23 to have the transformation take place otherwise. Also, as an alternative to the previously described mechanism for phase locking laser 3 and 45, the laser optical wave on an optical path 39 can be passed through an acoustic-optic modulator, sometimes called a Bragg Cell. The diffracted optical wave exiting the acousto-optic modulator will be Doppler shifted by an impinging-driving RF wave, that is translated into a sound wave in the acousto-optic modulator, and the so-called Bragg shifted-diffracted optical wave will exit the acousti-optical ~~modudulator~~ modulator with an optical frequency equivalent to the phase locked laser 45. The acousto-optically generated lightwave, at an equivalent frequency of the phase locked laser 45, is sent along optical pathway 13 and becomes the local oscillator input to heterodyne photoreceiver 15. An acousto-optically frequency shifted version of the light in optical path 39 can therefore replace the phase locked light of coherent optical source 45. Accordingly it is to be understood that changes may be made by those skilled in the art within the principle and scope of the inventions expressed in the appended claims.

AMENDMENTS TO THE ABSTRACT

Replace the abstract with the following replacement abstract:

A distributed sensing system for an optical fiber span wherein the geometric arrangement of the span provides one or more sensing zones with different sensitivities. The span is interrogated with a series of radiated optical pulses. The back-scattered signals are detected from positions along the optical fiber span and the received signals are processed to provide a measurement representative of acoustic pressure waves incident on the span at the positions.

AMENDMENTS TO THE CLAIMS

The attached claims represent new claims in the continuation application, replacing the claims in the parent application.

Listing of Claims

1.-22. (Cancel).

23. (New) A system comprising:

a span of optical fiber having sensing zone segments wherein signals incident to said span have a property of inducing light path changes at sensing zone segments that result in a back-propagating signal wherein each zone segment has a specialized sensing function;

a light source operative to provide a continuous wave (CW) optical signal;

a modulator operative to modulate the CW optical signal with a reiterative autocorrelatable form of modulation, said modulator providing the modulated CW optical fiber to the span;

an optical receiver joined to said span and capable of receiving a retrieved optical signal returned therefrom, wherein the retrieved optical signal comprises back-propagating portions of the illumination from sensing zone segments, said receiver operative to produce a radio frequency (r.f.)

counterpart signal of the retrieved optical signal; and

a processor operative to detect a reiterative autocorrelatable form of modulation from the counterpart signal in a corresponding plurality of different timed relationships with respect to the reiterative autocorrelatable form of modulation of the CW optical signal to give at least one signal for each zone segment.

24. (New) The system of claim 23, wherein at least one zone segment of said span is helically disposed.

25. (New) The system of claim 23, wherein said span has a length L and said light source is a laser having the capability to generate a lightwave signal with sufficient stability to retain coherency in propagation along said span for a distance at least equal to two times the length L.

26. (New) The system of claim 25, wherein the length L of said span is at least about 5 km.

27. (New) The system of claim 23, wherein said light source is a planar, ring-type laser.

28. (New) The system of claim 23, wherein said span of optical fiber comprises a single mode fiber optic cable.

29. (New) The system of claim 23, wherein said span of optical fiber is made from the polarization preserving type of optical fiber.

30. (New) The system of claim 23, wherein said span of optical fiber has a coating made of a thermoplastic material having the combined characteristics of a low Young's modulus and a Poisson's ratio below that of natural rubber, wherein the coating enhances the longitudinal component of strain variation derived from an acoustic wave signal whose wave front is incident to the optical fiber span from a direction at least in part having a lateral component in the direction along which the wave front propagates.

31. (New) A method for sensing comprising the steps of:

providing a span of optical fiber wherein signals incident to the span induce light path changes at sensing zone segments of the span responsive to the signals resulting in a back-propagating signal;

illuminating the span with a modulated continuous wave (CW) optical signal with a reiterative autocorrelatable form of modulation;

receiving a retrieved optical signal from the span, wherein the retrieved optical signal comprises a back-propagating portions of the illumination from locations along the span in response to induced light path changes;

producing a radio frequency (r.f.) counterpart signal of the retrieved optical signal; and

detecting the reiterative autocorrelatable form of modulation from the counterpart signal in a corresponding plurality of different timed relationships with respect to the reiterative autocorrelatable form of modulation of the CW optical signal to provide signals from sensing zone segments of said span.

32. (New) The method of claim 31, wherein said step of providing the span includes providing at least one sensing zone segment of the span in a helical disposition.

33. (New) The method of claim 31, wherein the span of optical fiber span has a length L, and the light source is a laser having the capability to generate a lightwave signal with sufficient stability to substantially retain coherency in propagation along the span for a distance at least equal to two times length L.

34. (New) The method of claim 33, wherein the length L of said span is at least about 5 km.

35. (New) The method of claim 31, wherein said light source is a planar, ring-type laser.

36. (New) The method of claim 31, wherein said span of optical fiber comprises a single mode fiber optic cable.

37. (New) The method of claim 31, wherein said span of optical fiber is made from the polarization preserving type of optical fiber.

38. (New) The method of claim 31, wherein said span of optical fiber has a coating made of a thermoplastic material having the combined characteristics of a low Young's modulus and a Poisson's ratio below that of natural rubber, wherein the coating enhances the longitudinal component of strain variation derived from an acoustic wave signal whose wave front is incident to the optical fiber span from a direction at least in part having a lateral component in the direction along which the wave front propagates.

REMARKS / ARGUMENTS

Claims 1-22 are currently pending in the application.

New claims 23-38 are added. No new matter has been added. Claims 1-22 are canceled.

Concerning changes to the specification, the title and the abstract have been amended to more accurately reflect the claimed invention. The paragraph at col. 33, lines 10-37 is amended to correct typographical errors.

The amended claims are supported in the specification as described hereinafter. Claim 23 has the same scope as claim 21 of the parent application with an additional limitation narrower in scope than the claims of parent patent, U.S. Patent No. 7,030,971.

Reconsideration and allowance of the claims as amended is respectfully requested.

The Examiner is invited to telephone James M. Kasischke, Attorney for Applicant, at 401-832-3653 if, in the opinion of the Examiner, such a telephone call would serve to expedite the prosecution of the subject patent application.

Respectfully submitted,
ROBERT M. PAYTON

14 April 2015

By_/JAMES M. KASISCHKE/_
JAMES M. KASISCHKE
Attorney of Record
Reg. No. 36562

PTO/SB/06 (09-11)
Approved for use through 1/31/2014. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

PATENT APPLICATION FEE DETERMINATION RECORD
Substitute for Form PTO-875

Application or Docket Number	Filing Date	
14/686,161	06/16/2015	☐ To be Mailed

ENTITY: ☒ LARGE ☐ SMALL ☐ MICRO

APPLICATION AS FILED – PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	RATE ($)	FEE ($)
☐ BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	
☐ SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	
☐ EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	minus 20 =	*	X $ =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*	X $ =	
☐ APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			
☐ MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	

APPLICATION AS AMENDED – PART II

AMENDMENT		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
	04/14/2015						
	Total (37 CFR 1.16(i))	* 16	Minus	** 20	= 0	x $80 =	0
	Independent (37 CFR 1.16(h))	* 2	Minus	***3	= 0	x $420 =	0
	☐ Application Size Fee (37 CFR 1.16(s))						
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
						TOTAL ADD'L FEE	**0**

AMENDMENT		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	X $ =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	X $ =	
	☐ Application Size Fee (37 CFR 1.16(s))						
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
						TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

LIE
/TRACEY BELL/

PTO/SB/06 (09-11)
Approved for use through 1/31/2014. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 14/686,161	Filing Date 06/16/2015	☐ To be Mailed

ENTITY: ☒ LARGE ☐ SMALL ☐ MICRO

APPLICATION AS FILED – PART I

FOR	NUMBER FILED (Column 1)	NUMBER EXTRA (Column 2)	RATE ($)	FEE ($)
☐ BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	
☐ SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	
☐ EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	minus 20 =	*	X $ =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*	X $ =	
☐ APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			
☐ MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	

APPLICATION AS AMENDED – PART II

AMENDMENT	04/14/2015	CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	* 16	Minus	** 20	= 0	x $80 =	0
	Independent (37 CFR 1.16(h))	* 2	Minus	***3	= 0	x $420 =	0
	☐ Application Size Fee (37 CFR 1.16(s))						
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
						TOTAL ADD'L FEE	**0**

AMENDMENT		CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	X $ =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	X $ =	
	☐ Application Size Fee (37 CFR 1.16(s))						
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
						TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

LIE
/STELLA LITTLE/